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REPORTS, PAPERS, DISCUSSIONS, AND MEMOIRS

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FIRE-BANKS FOR OIL STORAGE

By H. H. Hall,* M. Am. Soc. C. E.

To Be Presented June 3, 1925

Synopsis

During 1924 larger quantities of petroleum and petroleum products have been in storage in the United States than ever before. Considering the amount of this oil in storage and its generally inflammable nature, the fire loss has been remarkably low.

Refined oils (which comprise by far the largest part of oil storage in or near cities and towns), when ignited, simply burn quietly until they are extinguished or burned dry; but crude petroleums, and occasionally refined fuel oils, are liable to boil over while burning. In order to make the storage of these latter products as safe as that of the refined oils, it is necessary to surround the container with so-called fire-walls.

The service to be rendered by these structures is a peculiar one from an hydraulic standpoint, as their primary function is to withstand the single wave of oil thrown out by the "boil-over". In an effort to find the best possible design, the series of model tests here described was conducted, the outstanding result being a demonstration of the value of some form of flash-board or coping which will curl the advancing wave back on itself.

Introduction

The discovery of a number of extremely prolific petroleum pools in both Oklahoma and California during 1922 and 1923 has resulted, in spite of a rapidly growing market, in a considerable over-production of all forms of petroleum products. In round figures, oil in storage has increased since 1921 from 200 000 000 bbl. to more than 500 000 000 bbl. This phenomenal growth has fixed the attention of many petroleum engineers on the design and proper protection of oil storage, with the result that a number of advantageous changes have been made. One of the most obvious changes, brought about by this study, has been a material increase in the size of storage units—both of the reservoir and the steel-tank type. Concrete-lined reservoirs have been built to contain more than 3 000 000 bbl. (42 gal. each); and steel tanks holding 150 000 bbl. per unit are not uncommon.

Note.—This paper is issued before the date set for presentation and discussion. Correspondence is invited and may be sent by mail to the Secretary. Discussion on the paper will be closed in September, 1925, and, when finally closed, the paper, with discussion in full, will be published in *Transactions*.

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Among the changes looking toward better protection of the storage there has been a considerable extension in the use of fire-proof and vapor-proof roofs, and the addition of numerous devices which are intended primarily to prevent evaporation loss, but which incidentally improve fire protection by lessening or eliminating the escape of inflammable vapors.

Although in such carefully protected storage fires are a rather rare occurrence (particularly in California where the danger from lightning is small) the study of methods for guarding against the spread of fire has not escaped some scrutiny in connection with this general study of oil storage. Unfortunately, some of these products have a disconcerting habit of boiling over after burning for varying lengths of time. Recent studies have shown that these boil-overs are confined to crude, and, in some cases, to fuel, oils. In order to prevent the possible spread of burning oil from structures containing either of these products, it is necessary to surround them with a fire-bank or wall of such dimensions that it will not be topped by the sudden wave-like advance of the oil which has boiled out. Aside from this requirement, the fire-walls need not, in general, be able to withstand much static pressure. The boil-overs, while sudden and violent, do not as a rule discharge any large part of a tank's contents; and although occasional tank leaks occur, the complete collapse of a full tank is so rare as to justify the designer in almost neglecting this possibility. The fire-wall problem is, therefore, primarily a question of stopping a single wave of high velocity.

Lack of knowledge as to which oils are likely to boil over, as well as lack of attention to this principal requirement of fire-wall design, has had two unfortunate results. Occasionally earth fire-walls have been built so low as to be topped by burning oil; and frequently city authorities and fire protection engineers, in the absence of exact knowledge as to what emergency to expect and how to meet it, have insisted on excessive clearance distances and fire-wall requirements around oil storage. With a view to clearing up the general question of fire-wall design, both of the permanent and temporary types, Standard Oil Company of California decided to undertake a series of model tests. Ultimately, these included more than 1 000 miniature boil-overs (using water for most of the tests) directed against 66 differently shaped walls and other obstructions.

Apparatus

The principal item of apparatus used was a wooden trough representing, at a scale of 1 to 14, a segment extending radially from the center of a tank 115 ft. in diameter (see Figs. 1 and 2). At the tank end of this trough was placed a box from which the boil-overs could be discharged by jerking open a gate; the area of this box was made considerably larger relatively than that of a segment of the tank, with the thought that when a boil-over occurs, the frothing oil coming out of the tank is generally driven by the wind, so that most of it is concentrated on one side of the tank. The box was made adjustable so that the height from which the "spills" occurred could be varied, corresponding to different heights of tanks and refinery receiving "pans".

Model fire-walls were constructed, to the same scale, and placed at various locations in the trough. As shown in Fig. 1, the wall is at a distance corresponding to 100 ft. from the tank, this being common practice for walls surrounding tanks on comparatively level ground. A majority of the tests were made with the walls in this position; but data were also obtained for locations (to scale) 50 ft. and 20 ft. from the tank. Model walls of the following shapes were tested:

1.—Earth walls with a 1 on 1.5 side slope;
2.—Earth walls with a 1 on 1 side slope (Fig. 3, right);
3.—Vertical walls (Fig. 4, right); and
4.—Modifications of the foregoing, using copings of various sizes and shapes (see Figs. 3 and 4).

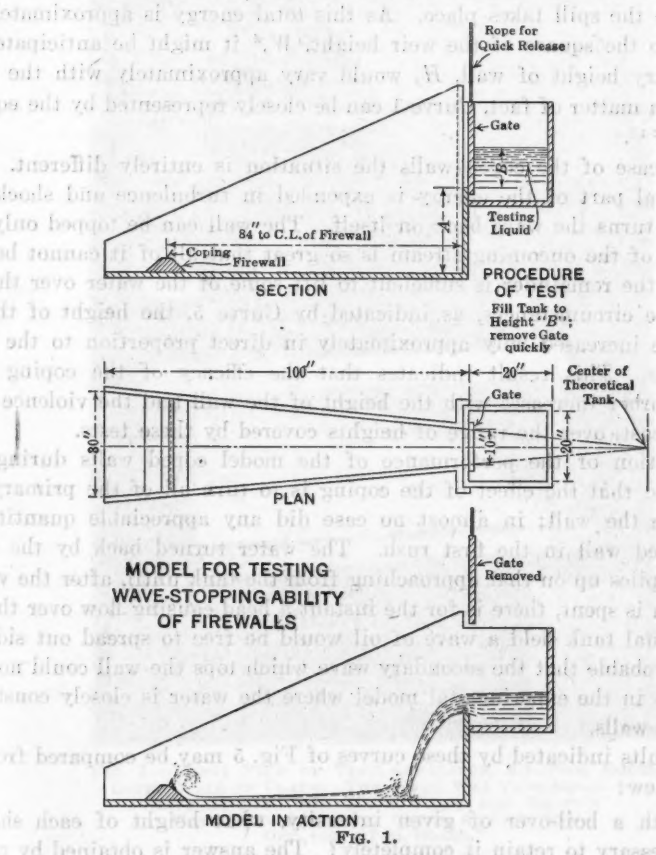


FIG. 1.

PROCEDURE AND RESULTS

1.—Preliminary Tests.—Some preliminary experimenting was first done to determine (1) the way in which the gate releasing the water must be jerked open in order to obtain uniform results; (2) the criterion which should be used in judging the performance of different wall shapes; and (3) the effect

of varying the height of the box from which the spill was discharged (Dimension *A*, Fig. 1). These tests are described in detail in the Appendix.

2.—Comparison of Standard Shapes.—The first main series of tests was run to compare the effectiveness of four of the most common shapes of wall now in use. The results are summarized by Curves 1 to 5, Fig. 5.

It will be noted that the curves for both shapes of earth wall, and for the plain vertical wall, are grouped close together, and have the same general shape and steep slope. Neither of these results is surprising, since all three shapes of wall depend primarily on height alone to stop the rush of water. This height, in turn, must depend approximately on the total energy of the oncoming stream, for the impact of the entire mass of water acts to push the topmost drops to a maximum height, with little loss in turbulence up to the time the spill takes place. As this total energy is approximately proportional to the square of the weir height, *W*,* it might be anticipated that the necessary height of wall, *H*, would vary approximately with the square of *W*. As a matter of fact, Curve 1 can be closely represented by the equation $H = 0.5\ W^{2.13}$.

In the case of the coped walls the situation is entirely different. Here, the principal part of the energy is expended in turbulence and shock when the coping turns the wave back on itself. The wall can be topped only when the energy of the oncoming stream is so great that all of it cannot be dissipated, and the remainder is sufficient to lift some of the water over the wall. Under these circumstances, as indicated by Curve 5, the height of the wall needs to be increased only approximately in direct proportion to the height of the weir. This result indicates that the efficacy of the coping as an energy absorber increases with the height of the wall and the violence of the wave—at least, over the range of heights covered by these tests.

Observation of the performance of the model coped walls during these tests showed that the effect of the coping is to turn all of the primary wave back inside the wall; in almost no case did any appreciable quantity pass over a coped wall in the first rush. The water turned back by the coping eventually piles up on that approaching from the tank until, after the velocity of approach is spent, there is for the instant a head causing flow over the wall. In any actual tank field a wave of oil would be free to spread out sideways, and it is probable that the secondary wave which tops the wall could not form so easily as in the experimental model where the water is closely constrained by the side-walls.

The results indicated by these curves of Fig. 5 may be compared from two points of view:

(*a*) With a boil-over of given intensity, what height of each shape of wall is necessary to retain it completely? The answer is obtained by reading from the curves of Fig. 5 the heights of different walls that will stop a given "height of weir", for instance, 3½ in. A graphic comparison of the results is shown in the top row of Fig. 6. On account of the steepness of the slope

* The energy represented by the elevation of the bottom of the weir box above the floor board is not considered available, since it appears as vertical velocity and is largely dissipated in shock.

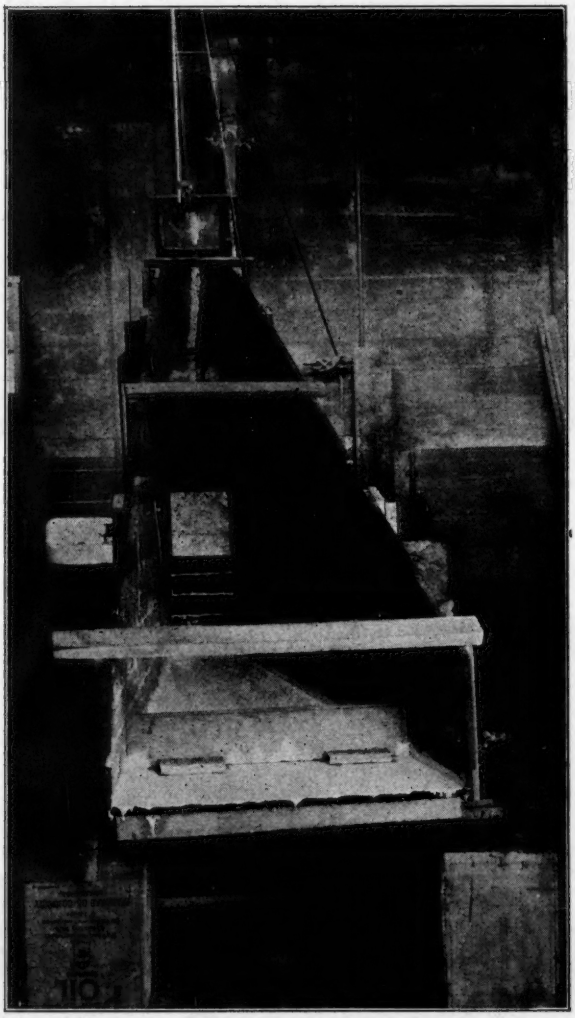
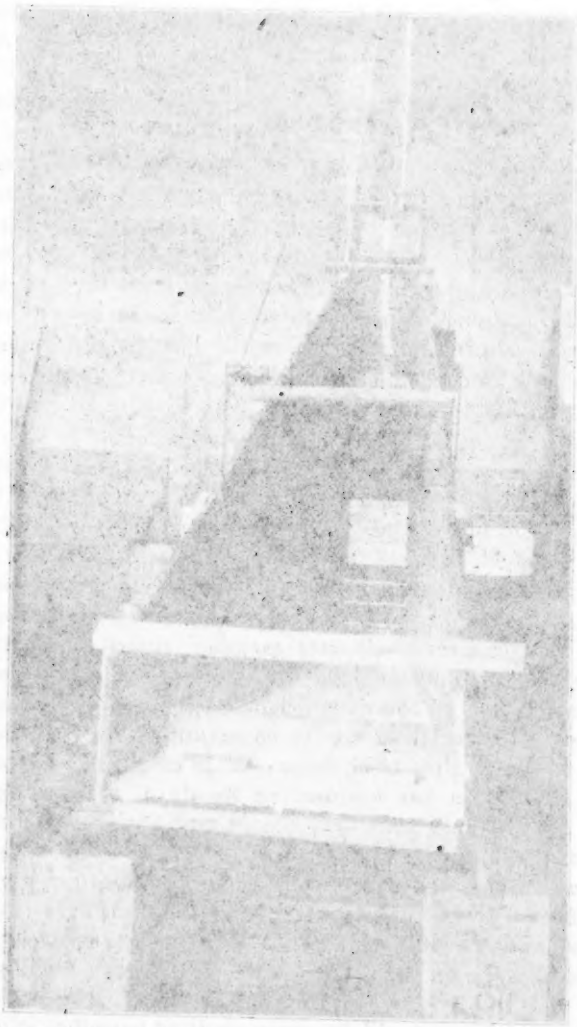


FIG. 2.—FRONT VIEW OF TEST APPARATUS, SHOWING MODEL COPED WALL IN PLACE. THE WALL WAS CONSIDERED TO HAVE STOPPED THE WAVE WHEN NOT ENOUGH WATER CAME OVER TO CAUSE ANY TO RUN OFF THE "TAIL-BOARD."



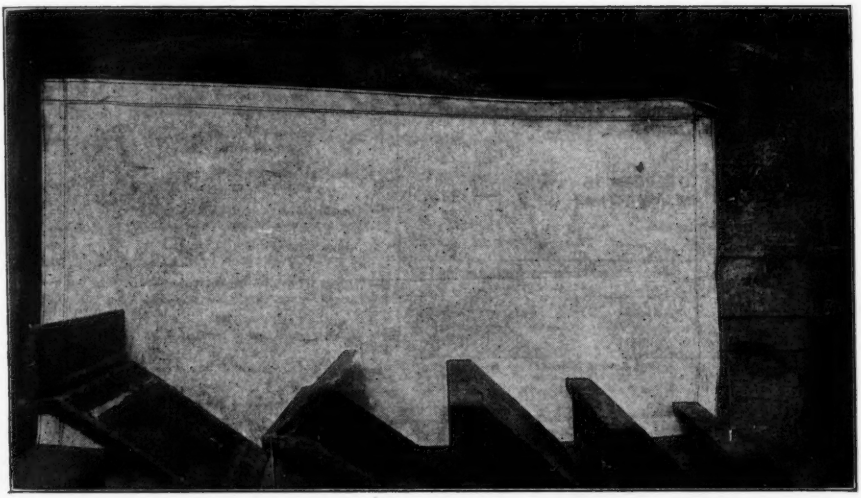


FIG. 3.—MODELS OF 1 ON 1 EARTH WALLS (PLAIN), AND 1 ON 1.5 EARTH WALLS WITH EXTENSIONS. ONLY THE FRONT HALF OF THE WALL WAS REPRODUCED, AS THE BACK HALF WOULD HAVE NO BEARING ON THE RESULTS.

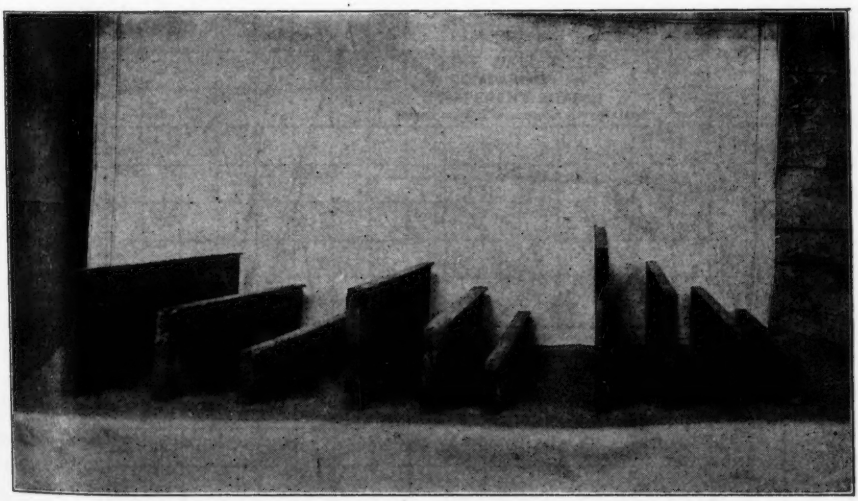
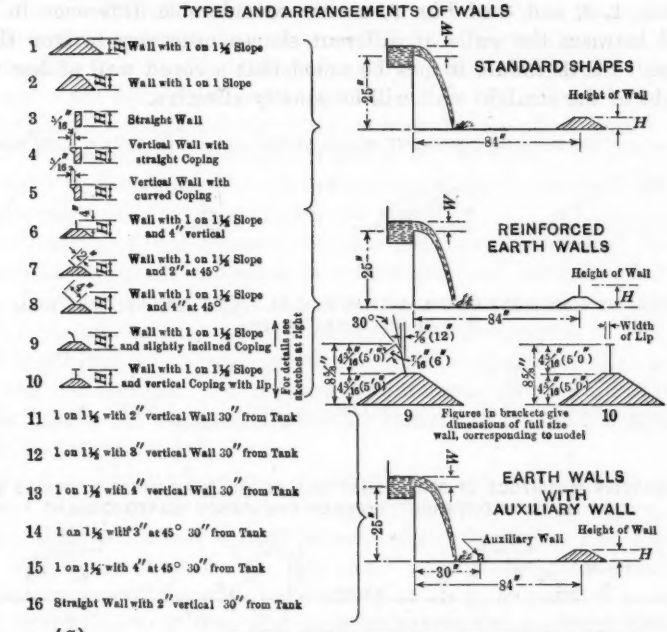


FIG. 4.—MODELS OF VERTICAL WALLS, PLAIN AND WITH COPINGS.


TYPES AND ARRANGEMENTS OF WALLS
1 Wall with 1 on 1½ Slope
2 Wall with 1 on 1 Slope
3 Straight Wall
4 Vertical Wall with straight Coping
5 Vertical Wall with curved Coping
6 Wall with 1 on 1½ Slope and 4″ vertical
7 Wall with 1 on 1½ Slope and 2″ at 45°
8 Wall with 1 on 1½ Slope and 4″ at 45°
9 Wall with 1 on 1½ Slope and slightly inclined Coping
10 Wall with 1 on 1½ Slope and vertical Coping with lip
For details see sketches at right
11 1 on 1½ with 2″ vertical Wall 30″ from Tank
12 1 on 1½ with 3″ vertical Wall 30″ from Tank
13 1 on 1½ with 4″ vertical Wall 30″ from Tank
14 1 on 1½ with 3″ at 45° 30″ from Tank
15 1 on 1½ with 4″ at 45° 30″ from Tank
16 Straight Wall with 2″ vertical 30″ from Tank
STANDARD SHAPES
Height of Wall
H
25″
84″
REINFORCED EARTH WALLS
30°
½″ (12″)
7/16″ (6″)
Width of Lip
8½″
4 3/16″ (5′ 0″)
4 3/16″ (6′ 0″)
9
10
Figures in brackets give dimensions of full size wall, corresponding to model
EARTH WALLS WITH AUXILIARY WALL
Auxiliary Wall
30″

(*a*)

NOTE: Models were made to represent a Tank 30′ high with C.L. of firewall 100′ from the shell. Actual Scale used was 1:14; so that roughly 1″=1′+

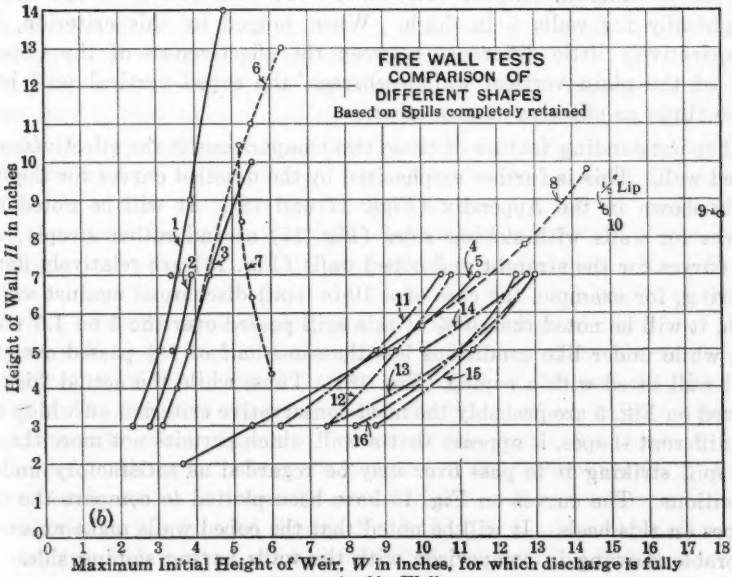

FIRE WALL TESTS
COMPARISON OF DIFFERENT SHAPES
Based on Spills completely retained
Height of Wall, H in Inches
½ Lip
(b)
Maximum Initial Height of Weir, W in inches, for which discharge is fully retained by Wall

FIG. 5.

of Curves, 1, 2, and 3 of Fig. 5, a very considerable difference in height is observed between the walls of different shapes necessary to stop this 3½ in. discharge. Furthermore, it may be noted that a coped wall of less than half the height of the straight wall will be equally effective.

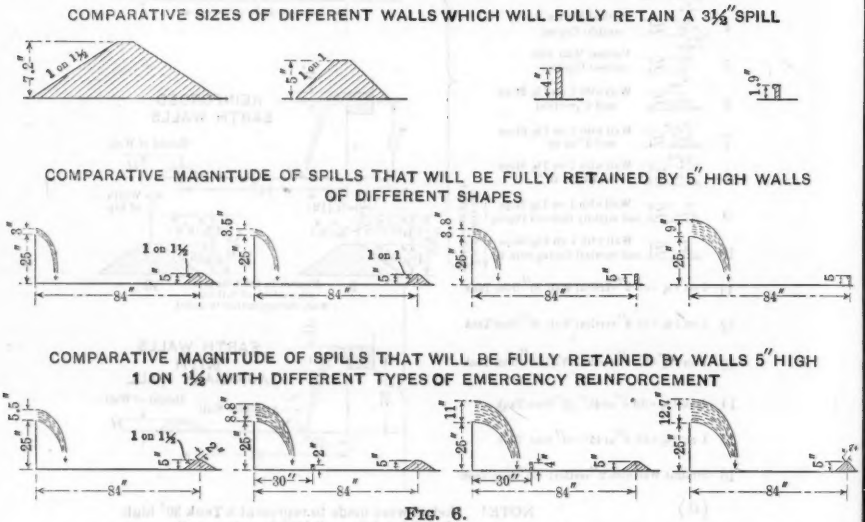


FIG. 6.

(*b*) With walls of the same height, what magnitude of boil-over will be stopped by different shapes? The middle row of Fig. 6 gives this comparison graphically for walls 5 in. high. When judged by this criterion, there is comparatively little difference between the effectiveness of the sloped walls and of the plain vertical walls; whereas, the coped vertical wall is almost three times as effective as any other.

The outstanding feature of these two comparisons is the effectiveness of the coped wall. This is further emphasized by the detailed curves for the different walls shown in the Appendix (Figs. 17 and 18). It will be noted that the curves for walls with sloping sides (Fig. 17) ascend rather steeply, whereas, the curves for the straight and coped walls (Fig. 18) are relatively flat. Considering, for example, the case of a 10-in. spill discharged against walls, 5 in. high, it will be noted that 40% of this spill passed over the 1 on 1.5 wall (Fig. 17), while under like conditions less than one-half of 1% passed over the vertical wall fitted with a coping (Fig. 18). Thus, while the actual "dry-points" plotted on Fig. 5 are probably the most conservative criterion on which to judge the different shapes, it appears that a wall which permits not more than 1% of the spill striking it to pass over may be regarded as satisfactory under most conditions. The curves on Fig. 19 have been plotted to compare the different shapes on this basis. It will be noted that the coped walls make an even more favorable showing in comparison with the walls having sloping sides.

3.—Methods of Reinforcing Standard Walls.—

(*a*) Extension on Top of Wall.—A method that has been used to some extent for increasing the effectiveness of earth walls has been to place on

top of them a vertical extension consisting of scrap steel plates. The models of walls with a 1 on 1.5 slope were equipped with such extensions 4 in. high (representing an actual height of about 5 ft., see model at the left in Fig. 3). The results are plotted as Curve 6 of Fig. 5. It will be noted that this extension resulted in comparatively little increase in the effectiveness of the wall, judged on the basis of complete stoppage of the wave. However, in testing this model it was found that the extension markedly reduced the percentage of the larger spills that passed over the wall.

Observation of the behavior of this coped wall indicated that it would be desirable to tip the extension in toward the tank instead of leaving it vertical. This was accordingly done, with the results shown on Curve 8, Fig. 5. It will be noted that this greatly increased the effectiveness of the wall. (See, also, Figs. 7 and 8.) Tests were run using extensions sloped at both 30° and 45° from the vertical. No appreciable difference in the results could be observed. As the 30° slope would probably be more convenient in actual practice, it is to be recommended.

This 4-in. "coping" proved so effective it was felt that an extension of half the height (still tilted back toward the tank) would give satisfactory results. This was tried, with the results shown by Curve 7 of Fig. 5.

It will be noted that even this small reinforcement materially increased the effectiveness of the wall, particularly at lower heights. The shape of this curve, indicating as it does that high walls will not stop such large boil-overs as low ones, is peculiar; but it has been carefully checked and found to be correct. The explanation seems to be that, with such a small coping, the long slope of the higher walls gives the force of the wave such a strong component in an upward direction that the coping is less able to break it up, than when placed on a lower wall with a shorter approach.

In discussing the practical application of these "copings", it was suggested that if they were sloped back toward the tank at an angle of 45°, or even 30°, there might be danger that burning oil discharged against the base of the fire-wall in a preliminary "slop-over" would so warp the sheets that they would not be in shape to function at the time of the main boil-over. Tests were accordingly run using the shape numbered "9" on Fig. 5, in which the coping was placed in an almost vertical position, with a short lip at the top turned back at a somewhat sharper angle. Only one height of this shape was tried, as shown by a single point on Fig. 5, but it will be noted that this point is well to the right of the others, indicating that this shape was the most effective of those tested. (See, also, Figs. 9, 10, and 11; the "wings" shown in Fig. 11 were used in testing the other coped walls, as it was felt that the corner effect observed in these models would not obtain in practice and tended to obscure the real effectiveness of the different walls). From the results obtained with this model it is felt that a wall and coping of the dimensions shown in the detailed Sketch No. 9, Fig. 5, would completely turn back the wave from the most severe boil-over likely to occur in practice, provided the wall is 50 ft. or more from the tank.

It was next suggested that for reinforcing division walls between two tanks, a vertical coping with a horizontal lip on top, as shown in Sketch No. 10,

Fig. 5, would be desirable. Tests were accordingly made on a model of this shape, using four different widths of lip. The result obtained with a ½-in. lip (corresponding, for the scale of model used, to a 7-in. extension on an actual coping) is plotted as the single point marked "10" on Fig. 5. It will be noted that this shape also proved very effective, so that a division wall of this shape with a 1-ft. plate at the top of the coping (giving a 6-in. lip on each side) can be counted on to turn back any boil-over, if the wall is at least 75 ft. from the tanks protected. Where conditions require that the wall lie closer to the tank, a wider lip would be desirable—perhaps with a maximum projection of 1 ft. on each side if the wall is within 40 or 50 ft.

(*b*).—Auxiliary Walls Close to Tank.—A study of the behavior of the waves created in those different tests suggested that by breaking the force of the wave just as it struck the ground the effectiveness of the fire-walls would be increased. Tests were accordingly made, first, with a small vertical wall placed 30 in. from the spill-box (corresponding in actual size to a vertical wall a little more than 2 ft. high, approximately 35 ft. from the tank shell). The results are shown in Curve 11, Fig. 5.

It will be noted that this small auxiliary wall had an important influence in increasing the effectiveness of the different types. Comparing Curves 11 and 7, (Fig. 5), it will be noted that in the case of the higher walls the same 2-in. strip used as a vertical wall near the tank was almost twice as effective as when placed as a coping on top of the wall. Since the auxiliary wall 35 ft. from the tank would be only about 60% as long as that 100 ft. away, the considerably smaller quantity of material needed for the closer wall is a further argument in its favor.

When 4-in. strips were used (corresponding approximately to a 5-ft. steel plate), this superiority of the closer wall was not so marked as far as stopping the wave was concerned (compare Curve 8 with Curves 13 and 15), but, of course, its advantage in requiring less material still remains.

Placing the auxiliary wall close to the tank either in a vertical position, or inclined back toward the tank, seemed to make comparatively little difference. Curve 12 applies to a 3-in. vertical wall, and Curve 14 to the same wall inclined at 45 degrees. Curves 13 and 15 give a corresponding comparison between 4-in. walls.

Curve 16 (Fig. 5) brings out the fact that the auxiliary wall close to the tank is just as much of a help to vertical fire-walls as it is to those inclined to a 1 on 1.5 slope. A 2-in. auxiliary wall close to the tank resulted in moving Curve 3 (for the plain straight wall) out to the position of Curve 16, which shift strikingly emphasized the effectiveness of breaking the force of the wave by having an auxiliary wall close to the tank.

The bottom row of Fig. 6 gives a graphical comparison of the effectiveness of the different types of reinforcement discussed. As indicated, the main fire-wall in each of these tests was a 5-in., 1 on 1.5 wall. Comparison of the sizes of the spills mentioned, with that which the same wall without any reinforcement will stop (shown as the first figure of the middle row) emphasizes the value of some type of reinforcement to ordinary 1 on 1.5 walls.

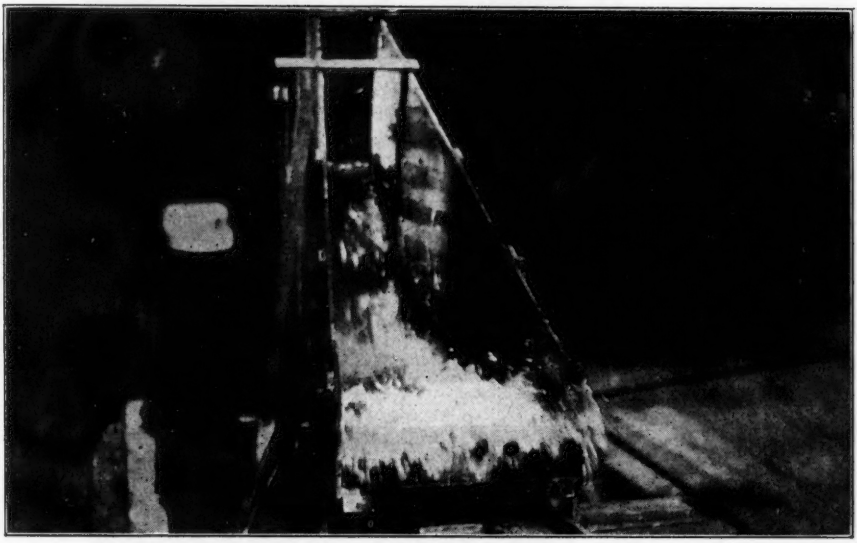


FIG. 7.—1 ON 1.5 WALL; 5 INCHES HIGH; 12-INCH BOIL-OVER 45 PER CENT. PASSING OVER WALL.

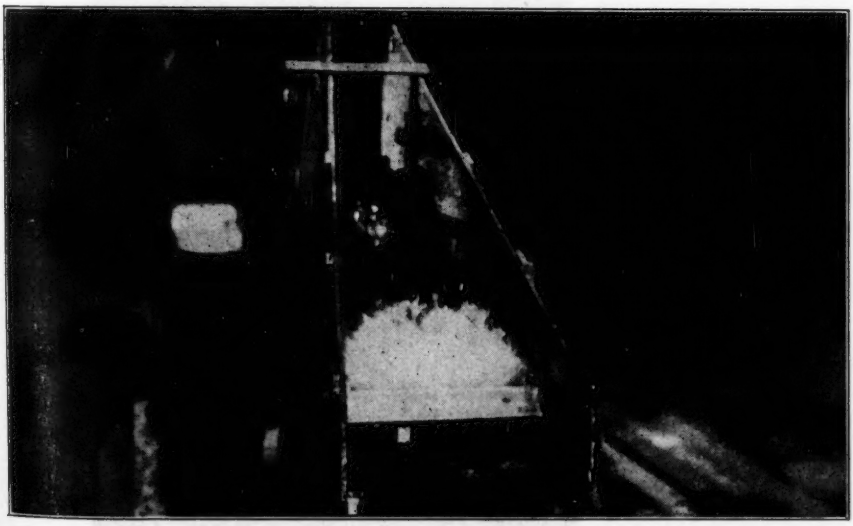


FIG. 8.—SAME WALL AS IN FIG. 7, WITH ADDITION OF 4-INCH COPING SLOPED AT 45 DEGREES TOWARD TANK. 12-INCH BOIL-OVER STOPPED.

FIG. 9.—15-INCH BOIL-OVER COMPLETELY STOPPED.

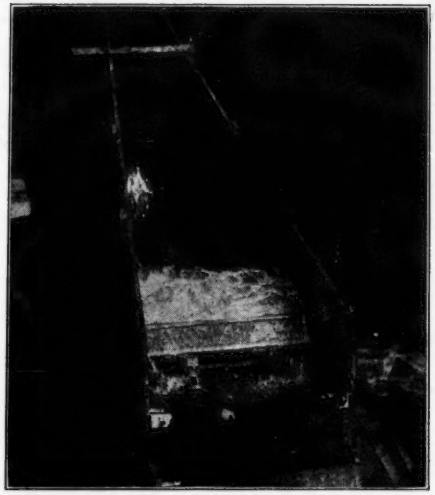


FIG. 10.—END OF 18-INCH BOIL-OVER; A SLIGHT QUANTITY PASSING OVER THE WALL AT THE CORNERS.

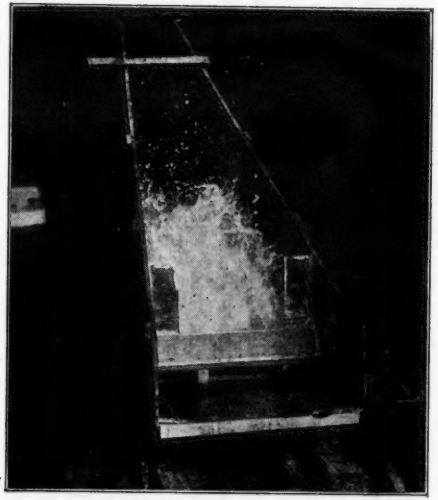
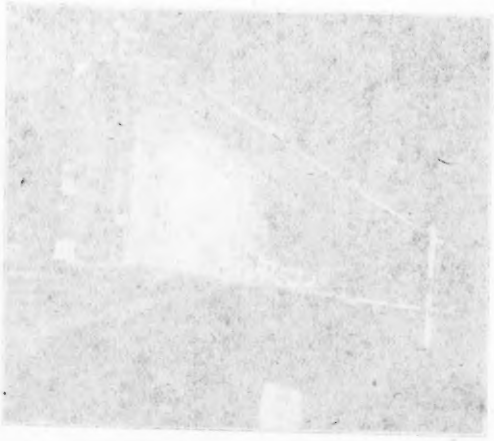


FIG. 11.—18-INCH BOIL-OVER COMPLETELY STOPPED, USING "WINGS" TO ELIMINATE CORNER EFFECT.

TESTS OF MODEL WALL No. 9 (FIG. 5).



(*c*).—Borrow-Pits, Etc., Close to Tank.—It was next decided to see whether a pit dug around the base of the tank in such a way that the falling wave would strike the ground surface approximately normally (with the idea of creating maximum turbulence), would produce an effect similar to that of the vertical auxiliary walls. The floor of the model trough was modified to provide such a pit 3 in. deep; the results are shown as Curve 3 of Fig. 12. The plain 1 on 1.5 wall is also plotted for comparison. It is evident that the value of the plain wall has been only slightly increased by this arrangement.

It was then suggested that a low earth wall built just outside the pit might increase its effectiveness. Curve 4 of Fig. 12 (which coincides with Curve 3) gives the results for a pit 2 in. deep with a 2-in. wall on the outside. This indicates that the wall on the outside makes a 2-in. pit as effective as a 3-in. pit without the wall; and, as this would be the logical shape in which to place the dirt, it is recommended. The slope toward the tank should be made as steep as soil conditions permit.

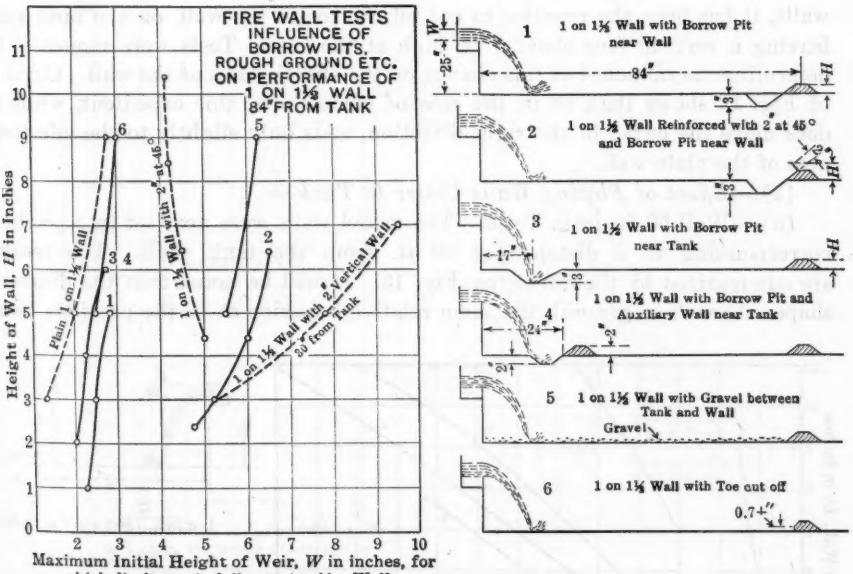

FIRE WALL TESTS
INFLUENCE OF BORROW PITS, ROUGH GROUND ETC. ON PERFORMANCE OF 1 ON 1½ WALL 84" FROM TANK
Height of Wall, H in Inches
Maximum Initial Height of Weir, W in inches, for which discharge is fully retained by Wall
Plain 1 on 1½ Wall
1 on 1½ Wall with 2" at 45°
1 on 1½ Wall with 2" Vertical Wall 50" from Tank
1 1 on 1½ Wall with Borrow Pit near Wall
2 1 on 1½ Wall Reinforced with 2" at 45° and Borrow Pit near Wall
3 1 on 1½ Wall with Borrow Pit near Tank
1 on 1½ Wall with Borrow Pit and Auxiliary Wall near Tank
5 1 on 1½ Wall with Gravel between Tank and Wall
Gravel
6 1 on 1½ Wall with Toe cut off
0.7+"

FIG. 12.

(*d*).—Borrow-Pit at Wall.—During the progress of the tests interest was expressed regarding the possible effectiveness of a borrow-pit on the tank side of an earth wall. The floor of the model trough was accordingly modified with results as indicated by Curves 1 and 2, Fig. 12. It will be noted that the pit next to the wall proved somewhat more effective than the one near the tank already described in Section (*c*) (compare Curve 1 with Curve 3), and considerably increased the effectiveness of a small coping at the top of the wall (compare Curve 2 with the dotted curve for "1 on 1.5 wall with 2 in.

at 45°"). This is a further argument in favor of using a coping on top of 1 on 1.5 walls; for there is generally a borrow-pit on the tank side of such walls.

(*e*).—Rough Surface Between Tank and Wall.—In actual practice the space between the fire-walls and tank is sometimes cleared of weeds with a road scraper, which leaves the surface quite smooth; in other cases, the weeds are simply plowed under, leaving a rough surface.

With a view to determining the influence of such a rough surface on a boil-over wave, a strip of tarred paper was laid on the bottom of the model trough, into which was bedded gravel approximately ¼ in. in diameter and less. To scale, these bits of gravel simulated clods about 4 in. high. The results of tests with this equipment are shown as Curve 5 on Fig. 12. It will be noted that the gravel had a marked effect in breaking up the force of the wave, and this enabled a wall of given height to stop a much greater spill than it could if the intervening space were smooth (compare Curve 5 with the dotted curve "Plain 1 on 1.5 Wall").

(*f*).—Toe Cut-Off 1 on 1.5 Walls.—In cleaning up around certain fire-walls, it has been the practice to cut off the toe of the wall, on the tank side, leaving a vertical face about 1 ft. high at the base. Tests were requested to determine the influence of this change on the effectiveness of the wall. Curve 6 of Fig. 12 shows that, as in the case of borrow-pits, this expedient, while it does move the curve in the right direction, adds only slightly to the effectiveness of the plain wall.

(*4*).—*Effect of Placing Walls Closer to Tank.*—

(*a*).—Wall 50 ft. from Tank.—The model walls were next set in a position corresponding to a distance of 50 ft. from the tank shell. The results are summarized by the curves on Fig. 13. It will be noted that the different shapes showed, in general, the same relative behavior as in the previous tests.

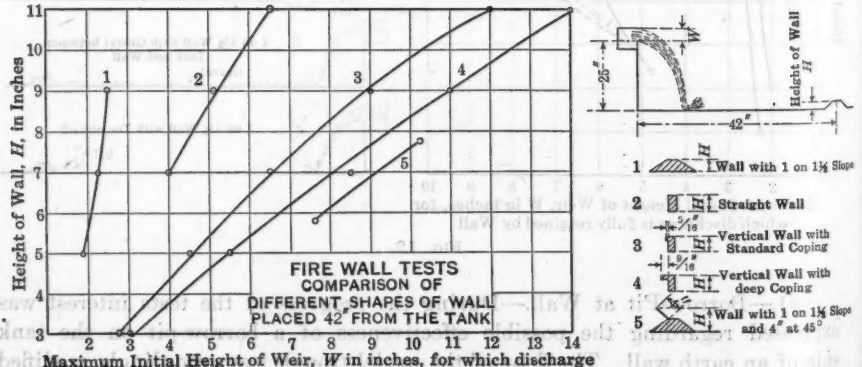


FIG. 13.

At this closer distance the effectiveness of the vertical wall, as compared with the 1 on 1.5 wall was relatively greater than at the 100-ft. spacing. On the other hand, the coping on top of the vertical wall did not result in such a

marked increase in its effectiveness as had been previously observed. This led to the suggestion that a heavier coping might be desirable; a comparison of Curves 3 and 4 of Fig. 13 indicates that doubling the width of the coping increased the effectiveness of the wall by about 20 per cent. The coping on top of the 1 on 1.5 wall showed the same marked effectiveness as in the previous tests (Curve 5 of Fig. 13).

(*b*).—Wall 20 Ft. from Tank.—When the model walls were moved in to a distance (17 in.) corresponding to 20 ft. from the tank shell, the differences in the behavior of the various shapes were not so marked. The curves on the upper half of Fig. 14 show the results when the boil-overs were discharged from the 25-in. height used in previous tests (corresponding to a 30-ft. tank); and the data on the lower half summarize the results of a few tests in which boil-overs were discharged against low walls from a height of 8½ in., corresponding to the 10-ft. "receiving pans" commonly used in refineries.

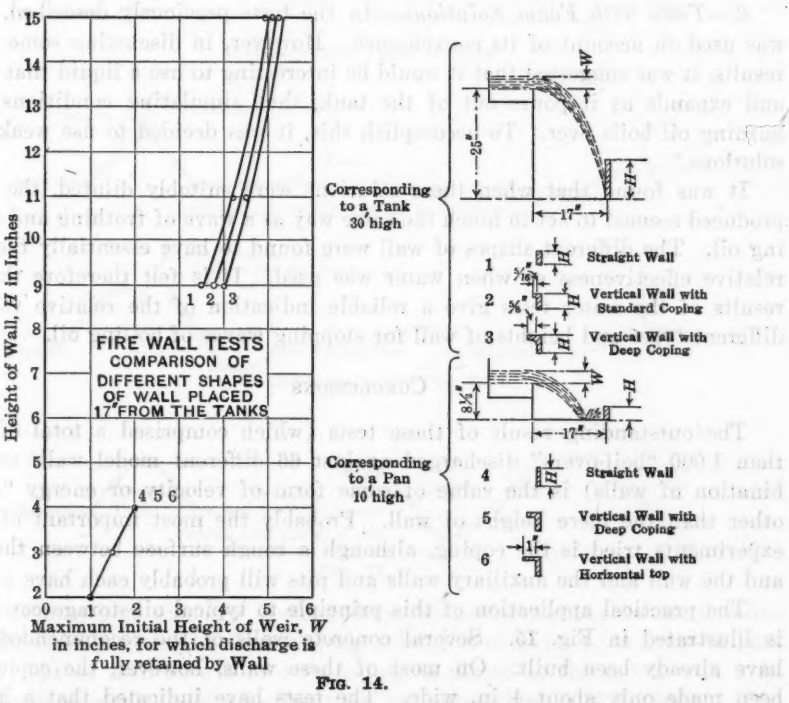

FIRE WALL TESTS
COMPARISON OF DIFFERENT SHAPES OF WALL PLACED 17" FROM THE TANKS
Height of Wall, H in Inches
Maximum Initial Height of Weir, W in inches, for which discharge is fully retained by Wall
Corresponding to a Tank 30' high
Corresponding to a Pan 10' high
1 Straight Wall
2 Vertical Wall with Standard Coping
3 Vertical Wall with Deep Coping
4 Straight Wall
5 Vertical Wall with Deep Coping
6 Vertical Wall with Horizontal top

FIG. 14.

It is felt that the small differences indicated by these tests (Test (4b)) are attributable mainly to the fact that, when the model walls were moved close to the tank, there was hardly room for wave action to occur. In practice, of course, these conditions would not hold. It seems likely that the advantages of copings observed in those previous tests where the wall was far enough away from the tank for wave action to develop, would make themselves felt to practically the same extent where actual walls are within 20 ft. of the tank.

5.—Reservoir Fire-Walls.—In connection with some contemplated strengthening of reservoir fire-banks, tests were requested to determine the influence of a small mound and borrow-pit at the toe of a reservoir slope.

As was the case with the vertical auxiliary walls near the tank, described under Test 4(b), the mound at the base of the slope served to break the force of the wave to such an extent as to enable a given height of main wall to stop a much larger wave; or, conversely, with a given intensity of boil-over to stop, the main wall can be made considerably lower if the auxiliary mound is built at the toe of the slope.

Since a relatively small quantity of earth is required to build this mound (both on account of its low height and small radius as compared with the main fire-wall), the total yardage of earth required to obtain a given degree of protection is 20 or 30% less when the mound is used, than when the main wall is built high enough to stop the wave without any auxiliary protection.

6.—Tests with Foam Solutions.—In the tests previously described, water was used on account of its convenience. However, in discussing some of the results, it was suggested that it would be interesting to use a liquid that froths and expands as it pours out of the tank, thus simulating conditions when burning oil boils over. To accomplish this, it was decided to use weak foam solutions.*

It was found that when these solutions were suitably diluted, the waves produced seemed to act in much the same way as a wave of frothing and steaming oil. The different shapes of wall were found to have essentially the same relative effectiveness as when water was used. It is felt therefore that the results of the water tests give a reliable indication of the relative value of different types and heights of wall for stopping waves of boiling oil.

Conclusions

The outstanding result of these tests (which comprised a total of more than 1 000 "boil-overs" discharged against 66 different model walls or combination of walls) is the value of some form of velocity or energy "killer" other than the mere height of wall. Probably the most important of those experiments tried is the coping, although a rough surface between the tank and the wall and the auxiliary walls and pits will probably each have a place.

The practical application of this principle to typical oil-storage conditions is illustrated in Fig. 15. Several concrete walls of the recommended form have already been built. On most of these walls, however, the coping has been made only about 4 in. wide. The tests have indicated that a heavier coping—say, 8 in. wide—will add considerably to the effectiveness of walls which are fairly close to tanks; and as this increase in the width would add a negligible amount to the cost, it would seem desirable.

As indicated by the curves on Fig. 13, a wall 5 ft. high (model height, 4.3 in.) with an 8-in. coping is as effectual as a plain wall 9.6 ft. high (model height, 8.2 in.). A 5-ft. coped wall of standard T-shape will require about

* Basic and acid liquids used to produce foam for extinguishing oil fires, see U. S. Bureau of Mines, *Bulletin No. 170*, p. 10.

¼ cu. yd. of concrete per lin. ft. at $30 per yd.; this would cost $7.50 per lin. ft. A wall, 9.6 ft. high, would contain about 0.6 cu. yd., costing about $18. From these figures it is apparent that a given degree of protection for turning back a wave will cost only about one-half as much with a coped as with a plain wall.

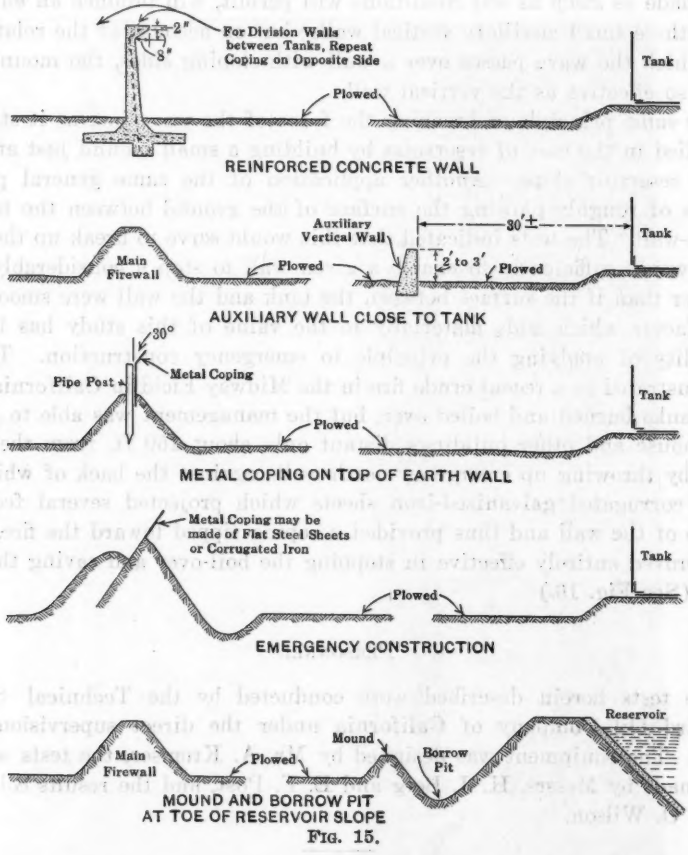


FIG. 15.

An even greater economy is effected by the use of copings on earth walls. Over these, on account of their sloping sides, waves have a tendency to pass readily; but as soon as a 3 or 4-ft. coping is placed at the top, a wall 5 ft. high becomes much more effective than an uncoped wall 15 ft. high. (See curves on Fig. 5.) Where scrap steel plates are available for building copings of the general form shown on Fig. 15, the cost will be very low. Even where new galvanized-iron sheets have to be purchased, the cost figures indicate that a given effectiveness can be obtained with a coped wall at about one-quarter the cost of the high earth wall.

Where local conditions permit, a low vertical auxiliary wall about 30 ft. from the base of the tank is an even more economical method of increasing the effectiveness of the main wall. This auxiliary wall breaks the force of

the wave and robs it of the energy required to carry it over a main wall that it could otherwise easily surmount. On account of the smaller radius of this auxiliary wall, only about 60% as much material is required to build it as for the coping on the main wall that would have equivalent effect.

A small mound 2 or 3 ft. high with a borrow-pit toward the tank, and the slope made as steep as soil conditions will permit, will produce an effect similar to these small auxiliary vertical walls; but on account of the relative ease with which the wave passes over a wall with sloping sides, the mound is not nearly so effective as the vertical wall.

The same principle of breaking the force of the wave just as it starts can be applied in the case of reservoirs by building a small mound just at the toe of the reservoir slope. Another application of the same general principle consists of roughly plowing the surface of the ground between the tank and the fire-wall. The tests indicated that this would serve to break up the energy of the waves sufficiently to enable a given wall to stop a considerably higher boil-over than if the surface between the tank and the wall were smooth.

A factor which adds materially to the value of this study has been the possibility of applying the principle to emergency construction. This was well illustrated in a recent crude fire in the Midway Field in California. Four large tanks burned and boiled over, but the management was able to save the pump-house and other buildings distant only about 160 ft. from the nearest tanks, by throwing up emergency earth walls against the back of which were placed corrugated galvanized-iron sheets which projected several feet above the top of the wall and thus provided a coping tipped toward the fire. These walls proved entirely effective in stopping the boil-over and saving the buildings. (See Fig. 16.)

Personnel

The tests herein described were conducted by the Technical Staff of Standard Oil Company of California under the direct supervision of the writer. The equipment was designed by Mr. A. Kremser, the tests were actually made by Messrs. H. J. Berg and E. F. Post, and the results collated by Mr. G. O. Wilson.

APPENDIX

Preliminary Tests to Study Theoretical Applicability of Model and Performance of Apparatus

Theory of Model Application.—Although it was never intended to make quantitative use of these model experiments, it was hoped that in spite of the small scale they would show relative efficiencies among themselves. A number of exhaustive studies of the application of models to various engineering problems have been presented in recent years. In their paper* describing the experiments with models of the Gilboa Dam, R. W. Gausmann, M. Am. Soc.

* *Transactions*, Am. Soc. C. E., Vol. LXXXVI (1923), p. 300.

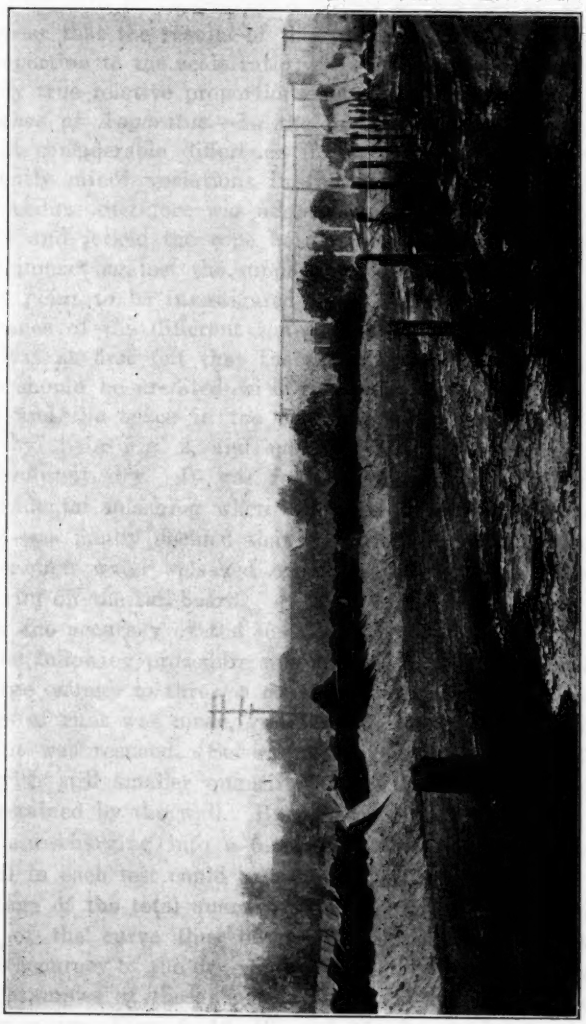
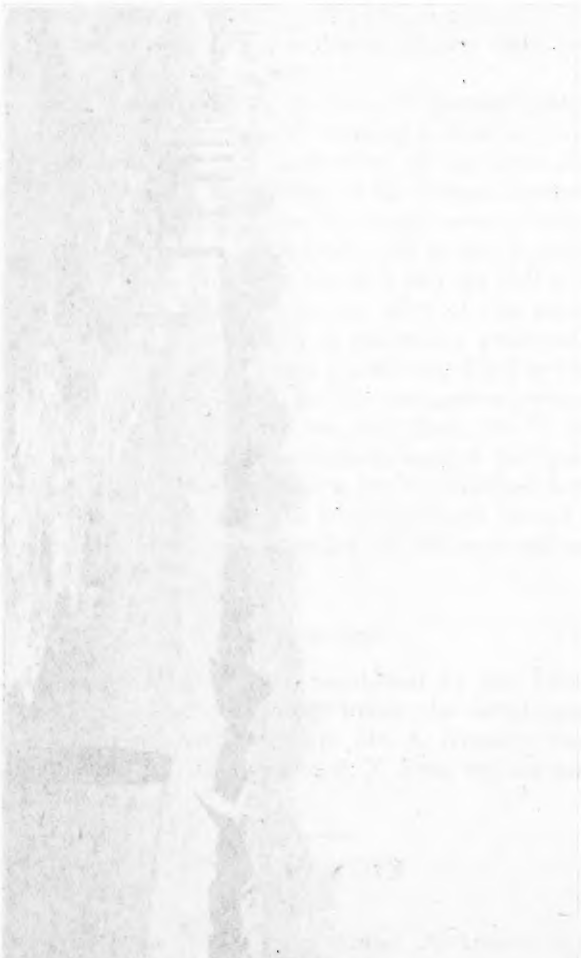


FIG. 16.—EMERGENCY WALL USED IN ACTUAL FIRE.



C. E., and C. M. Madden, Assoc. M. Am. Soc. C. E., stated that "if a model of a weir or channel is geometrically and mechanically similar to its prototype, the velocity will vary as the square root of the scale ratio."

In the model experiments here considered, the criterion of comparison is the height of wall which will be topped by various spills. As this height will be approximately proportional to the square of the velocity, and as the velocity, in turn, will be in proportion to the square root of the scale ratio, it would appear that the results of these experiments will be approximately in direct proportion to the scale ratio; or what is more important, will show approximately true relative proportions between different tests.

Performance of Apparatus.—In the first trials of the apparatus it was observed that considerable difference in the behavior of the wave resulted from apparently minor variations in the method of opening the gate. A standard procedure therefore was adopted in which the operator stood in a certain place and jerked the rope hard enough to throw the gate up with considerable impact against the supporting beam.

The next point to be investigated was the proper criterion for judging the performance of the different shapes and heights of model walls to be tested. It was at first felt that the maximum height of spill which any given shape should be credited with retaining was that for which the top of the wall and the space in the end of the trough outside of the wall (designated by *A* in Fig. 2, and spoken of hereafter as the "tail-board") remained absolutely dry. It was found, however, that this depended too much on accidental splashing when the wave hit the wall in some peculiar way; and it was finally decided that the criterion should be the condition where not enough water splashed over the wall to cause any measurable quantity to run off the tail-board.

To check the accuracy of the so-called "dry point" thus determined for each wall, the following procedure was adopted: Starting with a spill which would be large enough to throw a considerable percentage of water over the wall, a series of runs was made, gradually decreasing the size of spill until the dry point was reached. Several more runs were made after reaching this point with still smaller quantities, to make sure that these would be completely retained by the wall. By placing at the end of the tail-board a collector pan discharging into a 5-gal. can, the quantity of water passing over the wall in each test could be measured. These quantities were plotted as a percentage of the total quantity discharged in any given spill; and the intersection of the curve thus obtained with the base line gave a good check on the accuracy of the dry-point found. The curves of Figs. 17 and 18 are typical examples of these "percentage over" curves, whereas the final summarizing curves, Figs. 5, 12, 13, and 14, show only the dry points for the different sizes and shapes of wall. As explained (page 730), Fig. 19 compares the different shapes on the basis of 99% of the spill being retained, instead of 100% as in Figs. 5, 12, etc.

One other preliminary step before starting the actual comparison of different sizes and shapes of wall was to investigate the effect of varying the

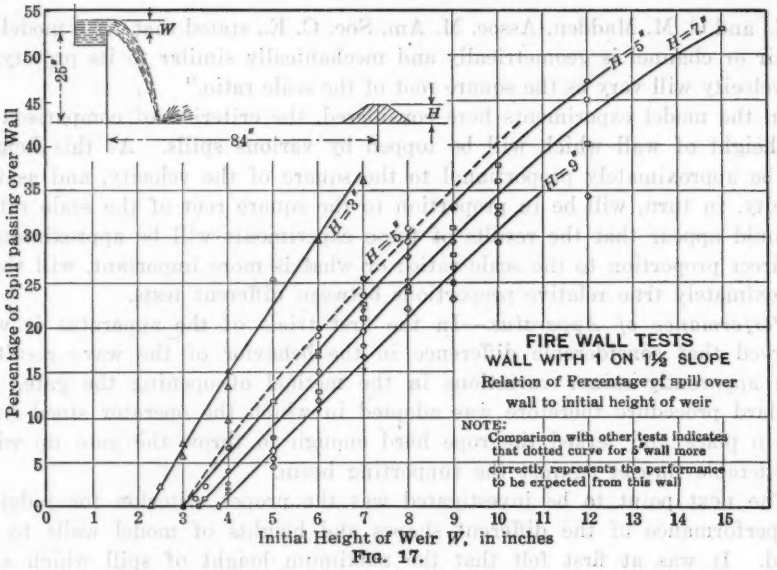

FIRE WALL TESTS
WALL WITH 1 ON 1½ SLOPE
Relation of Percentage of spill over wall to initial height of weir
NOTE:
Comparison with other tests indicates that dotted curve for 5" wall more correctly represents the performance to be expected from this wall
H=3"
H=5"
H=7"
H=9"
W
H
25"
84"
Percentage of Spill passing over Wall
Initial Height of Weir W, in inches

FIG. 17.

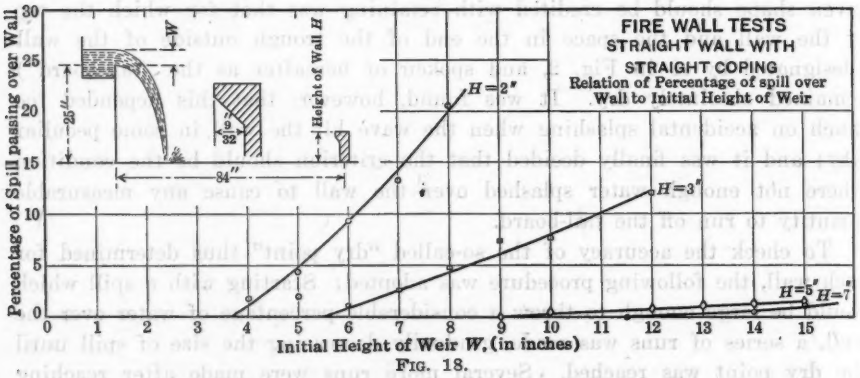


FIG. 18.

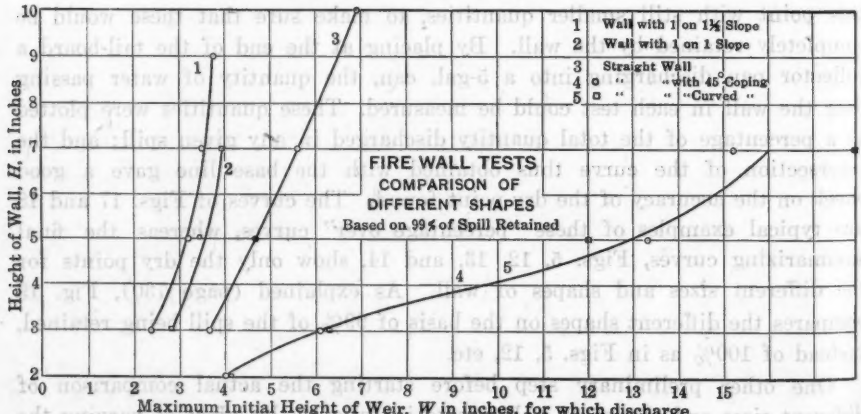

1 Wall with 1 on 1½ Slope
2 Wall with 1 on 1 Slope
3 Straight Wall
4 " " with 45° Coping
5 " " " Curved "
FIRE WALL TESTS
COMPARISON OF
DIFFERENT SHAPES
Based on 99% of Spill Retained
Height of Wall, H, in Inches
Maximum Initial Height of Weir, W in inches, for which discharge is fully retained by Wall

FIG. 19.

height of the box from which the spill was discharged (Dimension *A* in Fig. 1). The relative effectiveness of different walls was found to be (within reasonable limits of experimental error) essentially the same regardless of whether the spill was delivered from a high or low box. Accordingly, it was decided to run most of the main tests with the box set at 25 in. above the floor, which corresponds to an actual tank height of 30 ft.—this being the height most commonly used by Standard Oil Company of California.

ELEMENTS GOVERNING THE DEVELOPMENT OF HIGHWAY TRAFFIC*

By A. N. Johnson,† M. Am. Soc. C. E.

The purpose of this paper is to discuss the amount of future traffic upon American highways and to compare this with the traffic capacity of a two-lane road.

In order to do this, it is necessary to project what the progress is to be in the future, and this is always fraught with many uncertainties. Even if the physical facts on which to base a prediction are known, social forces may not continue to act as in the past, and thus new conditions arise that affect vitally the results. If the facts are known, and the forces, both social and economic, do not sensibly change, then one may predict with considerable assurance what the future may be expected to bring forth.

The physical facts upon which highway traffic rests are the number of vehicles using the road in a given time, the road mileage made by these vehicles during some definite period, and the mileage of the system of highways upon which the traffic moves. If, through a considerable period of time, these quantities have persisted at concordant rates, then future values may be predicted. In the instance of highway use, the values thus found will be approximately true, provided the causes that create a desire for the use of the motor vehicle do not change. For the present purpose, it is assumed that such will be the case; that people will not tire of the motor vehicle as a form of recreation; that, due to further congestion, increased traffic will not become the means that will strangle itself. All that is favorable to the continuance of travel by highway is to be assumed. With these conditions imposed, it is useful to endeavor to see what the future holds in store for the highways.

As has been indicated, the density of traffic over a system of roads depends on the vehicles using the system in a given time, together with the mileage made by these vehicles in a limited period, and the number of miles of highway in the system. The total number of motor vehicles is known. The average mileage per year per vehicle is variously estimated at 4 000 to 6 000 miles. Based on the gasoline consumption of the vehicles in certain localities, the average travel is about 5 000 miles per year. For the present purpose, the larger figure of 6 000 miles per year will be used.

There are in use (1924) approximately 18 000 000 motor vehicles, which would yield, on the assumption noted, a total annual traffic of 108 000 000 000 vehicle-miles, or an average daily traffic of nearly 300 000 000 vehicle-miles.

* Presented at the meeting of the Highway Division, New York, N. Y., January 22, 1925.

† Dean, Eng. Coll., Univ. of Maryland, College Park, Md.

This traffic, as every one knows, is far from evenly distributed over the approximately 2 500 000 miles of highways throughout the country. The bulk of the traffic is confined to a comparatively small fraction of the total road mileage.

It is a fact that few State highway systems, as at present developed, exceed 10% of the total road mileage of the State. For this discussion, it will be assumed that 75% of all highway traffic is carried on 10% of the highways. From these figures it is found that there is imposed on the main road systems an average daily traffic of 900 vehicles per mile.

Since 1917, under the direction of John N. Mackall, M. Am. Soc. C. E., Chairman and Chief Engineer of the State Roads Commission of Maryland, traffic counts have been made at regular intervals at approximately 200 counting stations on the State Highway System, which comprises very nearly 10% of the total road mileage. From these traffic counts there has been compiled the average number of vehicles per mile per day throughout each year since 1917.

In Table 1 the results thus obtained from actual traffic counts are compared with the amount of traffic as computed from motor-vehicle registration as previously outlined. It is seen from an examination of this table that the computed results are not widely divergent from those obtained from actual traffic counts and, at least, establish the fact that the amount of highway traffic is a linear function of motor-vehicle registration.

TABLE 1.—COMPARISON OF TRAFFIC DENSITY AS COMPUTED FROM MOTOR-VEHICLE REGISTRATION, APPLYING 75% OF THE TRAFFIC TO 10% OF THE TOTAL ROAD MILEAGE OF THE UNITED STATES, WITH THE TRAFFIC DENSITY ON THE STATE ROAD SYSTEM OF MARYLAND, AS FOUND FROM ACTUAL TRAFFIC COUNTS.

Year.	AVERAGE NUMBER OF VEHICLES THROUGH THE YEAR PER MILE, PER DAY.	
	As computed for the United States.	As counted on Maryland State Road System.
1917	250	258
1918	300	277
1919	375	355
1920	450	439
1921	500	537
1922	600	579
1923	740	726
1924	900	818

May limits be set to this highway traffic? May a point be reached where the increase in traffic would be at the same rate as the comparatively slow increase in population? As the number of motor vehicles is a prime factor in this calculation, an answer may be found if a study is made of the motor-vehicle registration curve.

It is logical to assume that eventually the limiting number of motor vehicles per population will be reached, and when such a point is reached, the rate of increase of the motor-vehicle curve will be equal to that for the population curve.

In Fig. 1 the motor-vehicle registration curve is shown, based on data furnished by the U. S. Bureau of Public Roads, as published by the National Automobile Chamber of Commerce. Likewise on this diagram is the popula-

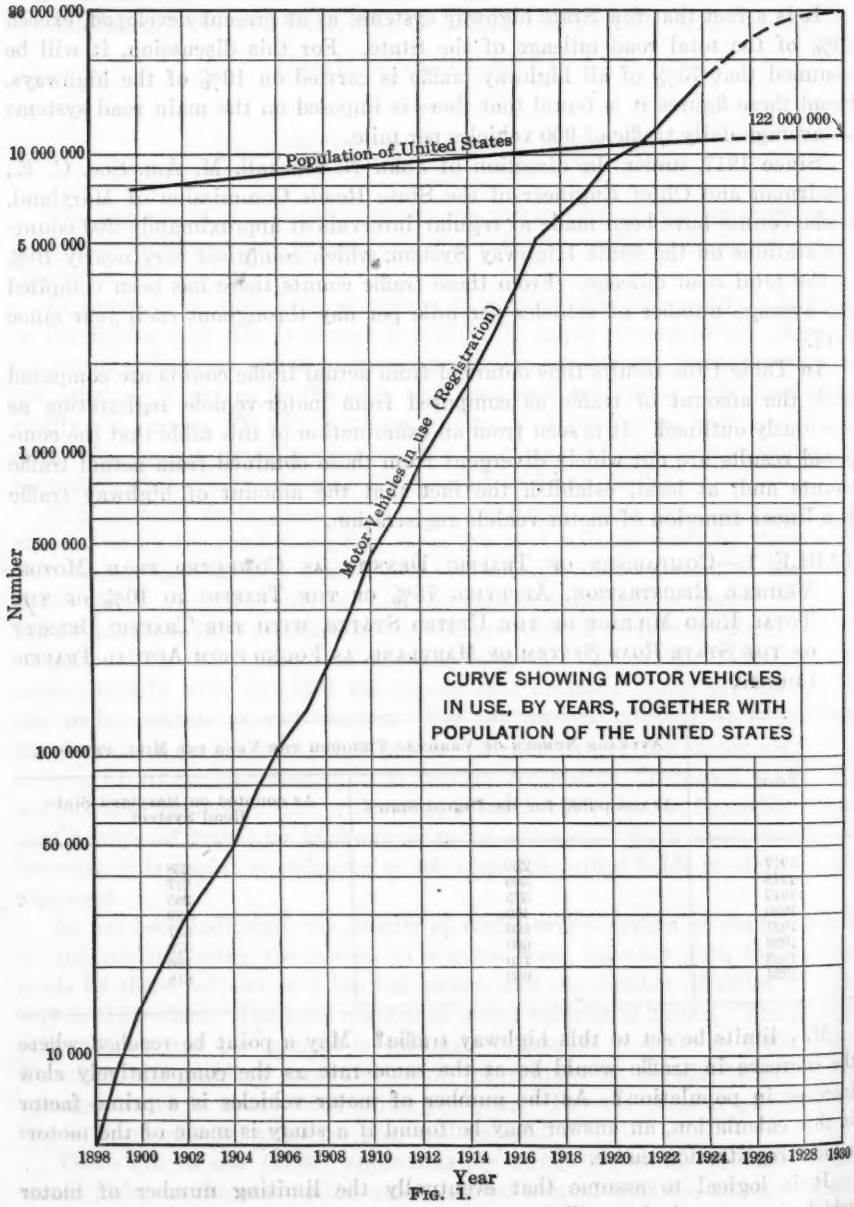

20 000 000
10 000 000
5 000 000
1 000 000
500 000
100 000
50 000
10 000
Number
122 000 000
Population of United States
Motor Vehicles in use (Registration)
CURVE SHOWING MOTOR VEHICLES IN USE, BY YEARS, TOGETHER WITH POPULATION OF THE UNITED STATES
1898 1900 1902 1904 1906 1908 1910 1912 1914 1916 1918 1920 1922 1924 1926 1928 1930
Year

FIG. 1.

tion curve. These curves have been platted on a semi-logarithmic scale; thus, the same rates of increase for each curve will exist at those points at which the curves are parallel. When the motor-vehicle registration curve becomes

parallel with the population curve, the saturation point in the market for motor vehicles has been reached. When does this occur?

To assist in projecting the motor-vehicle registration curve beyond the current year, the number of persons per automobile is perhaps the most direct method of arriving at an answer to this question.

In Fig. 2 a curve has been platted that shows the number of persons per motor vehicle for the past few years. It is noted that the number of persons per automobile in 1919 was 14; in 1924, 6.2. In California, in 1923, the number of automobiles per person, according to statistics published by the National Automobile Chamber of Commerce, reached 3, and in Iowa, 4, ranging from these values to 19 persons per motor vehicle in Alabama, the average for the United States for that year being 7.4. It is difficult to imagine that an average of less than 4 persons per automobile will be reached. A continu-

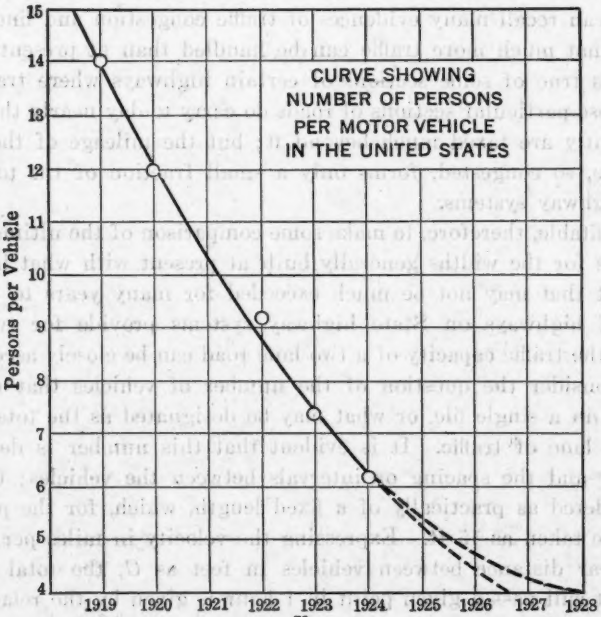


FIG. 2.

ation of the curve in Fig. 2 indicates that probably not earlier than 1926, and more likely about 1928, this point may be reached. On this latter assumption, the registration curve in Fig. 1 has been drawn, indicating a registration in 1928 of 29 000 000 motor vehicles. After that date, the rate of increase is shown as directly proportional to the increase in population. It is to be kept in mind that the assumption that has been made is based on a continuation of the desire to use motor vehicles that exist to-day; and as it is the intention to outline maximum conditions it is not necessary to consider what may happen from causes that would tend to reduce the amount of traffic.

An estimate of the average daily traffic to be expected by 1928, from the figures just given, may be made on a basis of calculation similar to that given

previously, that is, concentrating 75% of the traffic on 10% of the road mileage, which gives an average daily traffic of 1 500 motor vehicles per mile.

The mileage of improved roads is constantly increasing, many sections of roads now traveled by a comparatively small number of vehicles will experience, when improved, an increase in traffic. This traffic will have been drawn away from those roads now included in the 10%, that is, there will be a tendency to spread traffic over a larger proportion of the road mileage, all of which should have a tendency to reduce the density of traffic from the figure calculated—1 500 vehicles per day per mile.

From all the factors involved, and from the estimates made from these factors, it would seem to be safe to state that the present State highway systems, averaging about 10% of the total mileage, need not expect to be called on to carry in excess of an average daily traffic of 1 500 vehicles per mile. Every one can recall many evidences of traffic congestion and find it difficult to believe that much more traffic can be handled than at present. This undoubtedly is true of some sections of certain highways where traffic concentrates. These particular sections of roads do carry to-day nearly their capacity and frequently are taxed much beyond it; but the mileage of these sections of highways, so congested, forms only a small fraction of the total mileage of State highway systems.

It is profitable, therefore, to make some comparison of the ultimate capacity of highways for the widths generally built at present with what has been set as the limit that may not be much exceeded for many years to come. The majority of highways on State highway systems provide for two lanes of traffic, and the traffic capacity of a two-lane road can be closely ascertained.

First, consider the question of the number of vehicles that may pass a given point in a single file, or what may be designated as the total discharge of a single lane of traffic. It is evident that this number is dependent on the velocity and the spacing or intervals between the vehicles; the vehicles to be considered as practically of a fixed length, which, for the present purpose, may be taken as 15 ft. Expressing the velocity in miles per hour as V, and the clear distance between vehicles in feet as C, the total number of vehicles that will pass a given point in 1 hour is given by the relation:

$$N = \frac{5\,280\ V}{15 + C}$$

in which, 15 represents the average length, in feet.

It is known from observation that as the velocity of the vehicles increases, the spacing is varied. Whether this variation is directly as the velocity, or some other function of the velocity, is difficult to determine with any precision. There is some evidence, however, to indicate that the spacing between the vehicles varies approximately as the square of the velocity.

During special rush periods on the Washington-Baltimore Road, groups of vehicles moving 10 to 15 miles per hour, frequently were spaced as close as 15 ft., and other groups moving 25 to 30 miles per hour maintained an average spacing of 50 to 60 ft. Assuming that the average length of a vehicle is

15 ft., and that the clearance varies as the square of the velocity, the number of vehicles discharged per hour would be:

$$N = \frac{5\,280\ V}{15 + \frac{V^2}{15}}$$

If the first differential of this equation is equated to zero, it is found that N becomes a maximum when $V = 15$, that is, the interesting result is obtained that, if vehicles are spaced according to the square of the velocity, the maximum vehicle discharge will occur at 15 miles per hour, which, for a single line of traffic, equals 2 640 vehicles per hour.

The traffic capacity of a two-track highway was observed at a number of different points on the Washington-Baltimore Road on different days during a special rush of traffic on the occasion of the Laurel Races in October, 1924. Vehicles were counted at 5-min. and sometimes 10-min. intervals, through the peak of the traffic. Whenever the road became congested, a note was made. It was considered to be congested when a faster moving vehicle could not conveniently pass a slower one. As typical of these records that made on October 25, 1924, is given in Table 2.

TABLE 2.—Traffic Count, Baltimore-Washington Road, October 25, 1924.

Time, P. M.	Number of Vehicles.				Percentage of Vehicles.		Total vehicles, rate per hour.
	North.		South.		North.	South.	
	Automobiles.	Trucks.	Automobiles.	Trucks.			
4:30	23	1	15	1	60	40	480
4:35	19	1	15	..	57	43	420
4:40	18	..	17	1	50	50	432
4:45	54	..	19	1	73	27	888
4:50	52	..	22	..	70	30	888
4:55	47	1	11	1	80	20	720
5:00	44	2	7	..	86	14	636
5:05	49	..	20	1	70	30	840
5:10	104	1	8	1	92	8	1 368
5:15	111	1	12	1	90	10	1 500
5:20	126	..	7	..	95	5	1 596
5:25	93	2	15	..	86	14	1 320
5:30	110	1	6	..	95	5	1 404
5:35	112	..	10	..	91	9	1 464
5:40	...	..	..	..	..	..	.....

This count began at 4:30 P. M., and the lowest number of vehicles recorded was at the rate of 420 per hour, at which time traffic was about evenly divided in each direction. No inconvenience was noted, that is, traffic in either direction could maintain its speed of about 30 miles per hour, and was not held back by the occasional slower moving trucks, there being ample opportunity to pass. This condition prevailed until about 5:10 P. M., when it was observed that the road began to be congested. From the stream of traffic north, which was moving at an average speed of 25 to 30 miles per hour, vehicles could not turn out readily and pass a slower moving vehicle in front. This condition occurred when the traffic was between 800 and 1 000 vehicles per hour.

It was noted that for a traffic of 1 368 vehicles per hour, of which approximately 90% were moving in one direction, the road was uncomfortably crowded. On another occasion when the traffic reached a rate of 1 296 vehicles per hour, the same notation was made, but, at 1 000 vehicles or less, this crowded condition was not recorded. It should be stated that the observations were made by a number of recorders.

At a speed of 30 miles per hour, based on the formula as previously stated, the distance between the vehicles varying as the square of the velocity, the number of vehicles passing in a single line per hour would be 2 100. The greatest number observed was 1 500, the average speed being noted as 30 miles per hour. Therefore, the actual spacing between the vehicles (185 ft.) was considerably greater than that provided by the formula which assumes the spacing to vary as the square of the velocity, in which case vehicles would have a clearance of 60 ft. While the spacing was not uniform, yet the minimum clearance, as observed, varied from 50 to 60 ft.

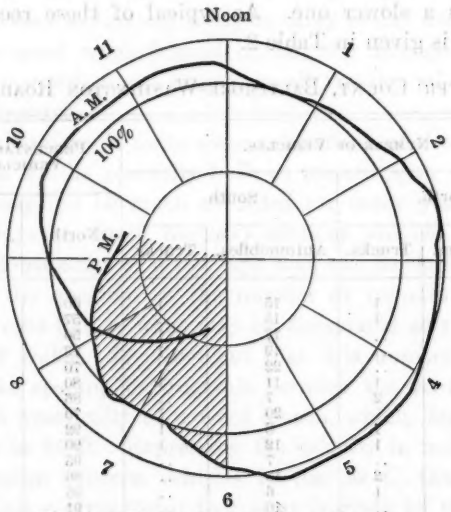


FIG. 3.—HOURLY VARIATION OF TRAFFIC.

From these conditions, the conclusion is reached that a two-lane road may carry traffic as great as 1 000 vehicles per hour without inconvenience to mixed traffic, the faster traffic having opportunity to overtake and pass the slower moving vehicles; and that for occasional peak traffic it will discharge readily, with traffic moving at an average speed of 25 miles per hour, at least to 1 600 vehicles per hour.

The next question is, what may be an average daily traffic if the recurrent high traffic load is not to exceed 1 000 vehicles per hour. This involves the diurnal variation of traffic. From results of various traffic studies, traffic in the mid-forenoon and late afternoon is 30 to 50% more than the average hourly traffic for the day. (See Fig. 3, which shows hourly variation of

traffic.* The hourly average is shown as 100 per cent.) Thus, if 1 000 vehicles are to represent the recurrent daily peak traffic, the average hourly traffic should be taken at approximately 600 to 700 vehicles. For a 12-hour day, this would give an average daily traffic of 7 200 vehicles, which can be accommodated on a two-track road without congestion.

In order to determine the average daily traffic that may be maintained throughout the year, the seasonal variation of traffic must be studied. In the vicinity of Baltimore, which is perhaps illustrative of many sections, it is found that the average daily traffic, during the period from June through October, is about three-fourths greater than the average daily traffic for the year. (See Fig. 4, which shows the seasonal variation of traffic near Baltimore, platted as percentage of daily average, shown as 100%, for 1917-18-19-20.) If 7 200 vehicles per day is to represent the high seasonal average, then the yearly average should be taken at 4 000 vehicles per day, that is, there may be throughout the year an average daily traffic of 4 000 vehicles per day without causing congestion on a two-track road, allowance being made for the general increase in traffic due to seasonal variation and for the normal increase due to hourly variation throughout the day.

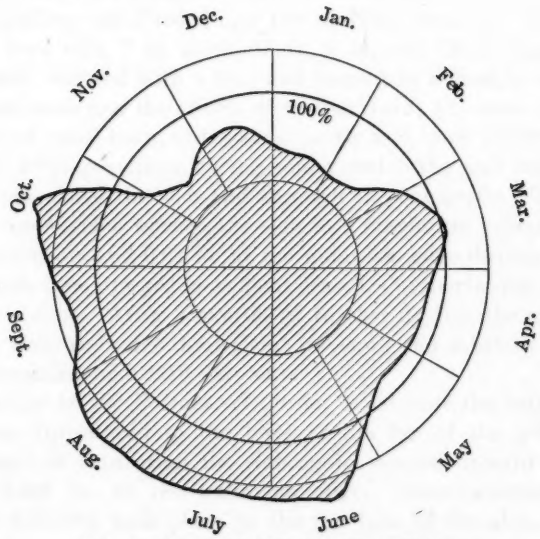


FIG. 4.—SEASONAL VARIATION OF TRAFFIC NEAR BALTIMORE, MD.

It was previously concluded that the largest probable expansion that may be reasonably expected in motor traffic, assuming 75% of the total traffic to be placed on only 10% of the roads, is an average daily traffic of 1 500 vehicles per mile, which is a little more than one-third the capacity of a two-track road.

With the highway systems built two lanes wide, supplemented by an increasing mileage of improved side roads, as well as extensions to the State roads

* Adapted from data on page 136 of California Highway System by the U. S. Bureau of Public Roads, 1920.

themselves, it is not reasonable to expect that any general congestion of traffic will occur for many years to come. Congestion, however, will continue increasingly to occur at certain points where traffic tends to concentrate, until the forces which attract traffic to these centers cease to act. It may well be that the very congestion itself will cause such a point to be no longer a center of attraction. The traffic will stifle the very thing that attracts it. This is happening and will happen again unless means can be found to prevent continued congestion by additional roads, wider roads and streets, the dispersion of certain business activities, and, in general, the providing of a greater area for the traffic to be accommodated.

On the whole, however, engineers are proceeding wisely and sufficiently in the design of the larger proportion of the mileage of improved roads if a two-lane width is provided.

THE EFFECT OF MOISTURE ON CONCRETE*

By W. K. Hatt,† M. Am. Soc. C. E.

Synopsis

This paper reports investigations conducted by the Engineering Experiment Station of Purdue University in co-operation with the U. S. Bureau of Public Roads, and reviews the literature on the measurement of the volume changes in Portland cements and concretes.

The primary purpose of the investigations was to measure the maximum warping and surface deformations produced in a concrete road slab as a result of a non-uniform distribution of moisture, to give a basis for estimating possible initial stresses. The tests also yield data of expansion and contraction of concrete, useful in the design of concrete structures.

The investigation was divided into two sections, namely: (1) Observations on a concrete road slab, 7 in. thick, 18 ft. wide, and 25 ft. long, resting on a porous sub-grade, covered with a tent and housed in a shed to control the distribution of moisture and the effects of temperature; (2) tests of strength and length changes of small beam units, some partly and some uniformly saturated.

Slab While Drying.—After curing under water the slab was dried by circulating air both above the slab and through the sub-grade. The more rapid drying of the top surface warped the slab to a maximum upward deflection of 0.12 in. at the corners and 0.04 in. at the unbroken edge during a period of 40 days, after which time upward movement ceased, the shortening of the diagonal being 0.0075 per cent. After 3 months of further drying, the slab had become approximately uniformly dry throughout its depth and substantially level, with a diagonal shortening of 0.0210 per cent.

Slab Saturated on the Bottom.—In order to saturate the bottom of the slab, water was then introduced to the level of the top of the gravel sub-grade. During 110 days of saturation the slab again warped upward 0.20 in. at the corners and 0.066 in. at the unbroken edge. Simultaneously, a diagonal shortening of 0.0070% took place in the top face of the slab, of which 46% occurred in 2 hours and nearly all in 2 days. The shortening was caused by the expansive force of the saturated lower part of the slab, and occurred without a change in moisture content or temperature of the top layers. Assuming an elastic condition and a modulus of elasticity of 5 000 000 lb. per sq. in., a compressive stress of 350 lb. per sq. in. in the top is indicated. The level of the water was finally raised, but the concrete at the bottom apparently had become impervious and no further warping occurred. Then the surface was covered with saturated burlap to simulate the effect of prolonged rain.

* Presented at the meeting of the Highway Division, New York, N. Y., January 22, 1925.

† Prof. of Civ. Eng., School of Civ. Eng., Purdue Univ., Lafayette, Ind.

Daily changes in the temperature of the slab resulted in differential warpings, depending on the degree of saturation and the temperature gradient. A typical daily change in air temperature above the slab of 42° Fahr. resulted in a variation of 3° Fahr. from top to bottom of the slab. The accompanying downward deflection of the corner due to this warping was 0.023 in., and the expansion of the surface, 0.0015 per cent. The movements due to this warping may be compared to 0.20 in. deflection and a shortening of 0.0057% due to the saturated sub-grade.

Loading tests were made on the corner of the slab for three conditions of warping.

The Beams.—Tests were conducted on concrete beams 4 in. by 7 in. by 4 ft.; some were uniformly wet, some uniformly dry, and some warped by non-uniform moisture distribution. The transverse strength was determined for dry, saturated, and partly saturated beams.

Beams uniformly saturated had a strength ranging from 80 to 85% that of dry beams, the average value being 82.0 per cent. Compression tests of wet concrete cylinders exhibited a strength of 75 to 83% that of dry cylinders, the average being 79.0 per cent.

Certain beams, previously dried from 3 to 4 months, were warped by saturating one face. In so doing the dry face was compressed for a small depth of saturation, and extended for medium and for maximum saturation. (See Appendix I.)

The dry face was tested as the tension face in a transverse flexure test. The variations in transverse strength for these various moisture conditions have been expressed in percentage values, 100% representing the completely dried specimens. The beams having a low depth of saturation and a shortened dry face exhibited a strength of from 109 to 127%, or an average of 118%; for medium saturation and slight extension of the dry face, the strength varied from 83.6 to 96.5%, or an average of 88.7%; for maximum saturation and greater extension of the dry face the strength was 80.7 per cent.

When the wet face was broken in transverse flexure these values became 83.5, 71.3, and 76.6%, respectively.

Volume Changes of Cements and Concretes.—Measurements, begun 2 days after moulding, of the volume changes in specimens of several brands of neat cements varied greatly. Expansion in water during 10 days was from 0.03 to 0.056 per cent. Contraction in air during 90 days subsequent to immersion was from 0.052 to 0.142 per cent.

Gravel concrete, 1 : 2 : 3½ (Cement F), expanded 0.005% during 40 days in water, and contracted 0.041% during 90 days in air and 0.050% during 30 days in an oven. Gravel concrete, 1 : 1½ : 3 (Cements A and D), expanded 0.005% in water, and contracted 0.015% in air and 0.0225% in the oven during the same periods.

Introduction

The investigation of the changes of shape of a concrete road slab caused by unequal moisture distribution, together with subsidiary tests described in this

paper, was suggested by A. T. Goldbeck, Assoc. M. Am. Soc. C. E., Chief of the Division of Tests and Investigations, of the U. S. Bureau of Roads, as a part of a co-operative work between the Bureau, T. H. MacDonald, Chief, and the Engineering Experiment Station of Purdue University, Dean A. A. Potter, Director.

The tests were made at Purdue University under the supervision of the writer and Professor R. B. Crepps. Mr. A. C. Benkelman was in direct charge, assisted by Mr. E. Gustavsen, both of the Staff of the U. S. Bureau of Roads. Mr. R. E. Mills, of the Engineering Experiment Station of Purdue University, assisted from time to time. Special acknowledgment should be made of the painstaking care in observations and the devotion to the tedious program of measurements contributed by Mr. Benkelman.

In these studies the following matters were examined:

1.—The maximum distortion (including deflection and fiber deformations) produced in a concrete road slab 18 ft. wide, 25 ft. long and 7 in. thick by a non-uniform distribution of moisture.

2.—The effect of moisture changes on the modulus of rupture and compressive strength of concrete, determined by subsidiary tests on (1) beams, 4 in. by 7 in. by 4 ft., and (2) cylinders, 6 in. in diameter by 12 in. long.

3.—The volume changes in the concrete beam specimens due to exposure, including warping due to partial saturation.

The approximate number of observations involved in the entire study was:

Type.	Number.
Deformation	40 000
Deflection	3 000
Strength	600
Weight	1 000
Temperature	1 500

Description of the Test Slab

The one-course concrete slab was 7 in. thick, 18 ft. 0 in. wide, and 25 ft. 0 in. long, with a longitudinal doweled center joint. A sub-grade, consisting of a 4-in. layer of coarse gravel, was held in an impervious wooden sub-base, the sides of which extended above the surface of the slab. The slab was housed in a shed and further protected under a tent. (Figs. 1 and 2.) It was cast on September 12, 1923. The subsequent treatment was as follows: (1) Cured under water for thirty days, until October 12, 1923; (2) the water removed and the slab dried for 188 days, until May 28, 1924; (3) the sub-grade saturated for 108 days, until October 20, 1924; and (4) the top covered with wet burlap.

Materials

A mixture of two brands of standard Portland cements, A and D, was used in one half-section of the slab and a single brand, F, in the other. The results of the usual standard tests of the cements are given in Table 1.

Note.—When the word "dry" is used in this paper, it refers to condition of hardened concrete and not to consistency of fresh concrete.

TABLE 1.—TEST OF CEMENT.

Brand.	Percentage, H_2O.		Percentage retained on 200-mesh sieve.	Time of Setting.				Soundness.	Tensile Strength, in Pounds.	
				Initial.		Final.				
	Normal consistency.	Mortar.		Hours.	Minutes.	Hours.	Minutes.		7 days.	28 days.
A and D mixture, equal quantities..	24	10.5	17.17*	2	10	5	15	O. K.	297	373
D	23	10.3	20.8*	2	35	5	20	O. K.	242	326
A	24	10.5	22.6*	4	00	5	55	O. K.	255	327
F	25	10.7	19.1	3	35	5	15	O. K.	220	333

* Different samples.

The aggregates were washed sand and gravel from the Western Indiana Sand and Gravel Company at Lafayette, Ind.

The results of the sieve analysis and miscellaneous tests of the aggregates are given in Table 2.

TABLE 2.—TESTS OF AGGREGATES.

Coarse Aggregate, Unit Weight = 102.5 lb. per cu. ft.
Fine " " " = 106.8 " " " "
Fineness Modulus of Coarse Aggregate = 7.32.
Fineness Modulus of Fine Aggregate = 3.17.
Fineness Modulus of Combined Aggregate = 5.90 for a 1 : 1.5 : 3 mix.
= 5.77 for a 1 : 2 : 3.5 mix.

SIEVE ANALYSIS OF GRAVEL.
(Tyler Standard Sieves.)

	Total Percentage Retained on Each Sieve.								
Sieve sizes	1½ in.	¾ in.	⅜ in.	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100
Percentage	0	46	87	98	99	99	99	99	100

SIEVE ANALYSIS OF SAND.
(Tyler Standard Sieves.)

	Total Percentage Retained on Each Sieve.						
Sieve sizes	⅜ in.	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100
Percentage	0	0	3	38	77	97	99

The coarse aggregate was separated into three sizes: Between the 2-in. and 1-in. screens; between the 1-in. and the ½-in. screens; and between the ½-in. and the ¼-in. screens. It was then recombined in such proportions as to give maximum density according to Fuller's maximum density curve. The consistency of the mix was checked by the slump-cone method. All materials, including water, were weighed for each batch.

The properties of the concrete are listed in Table 3.

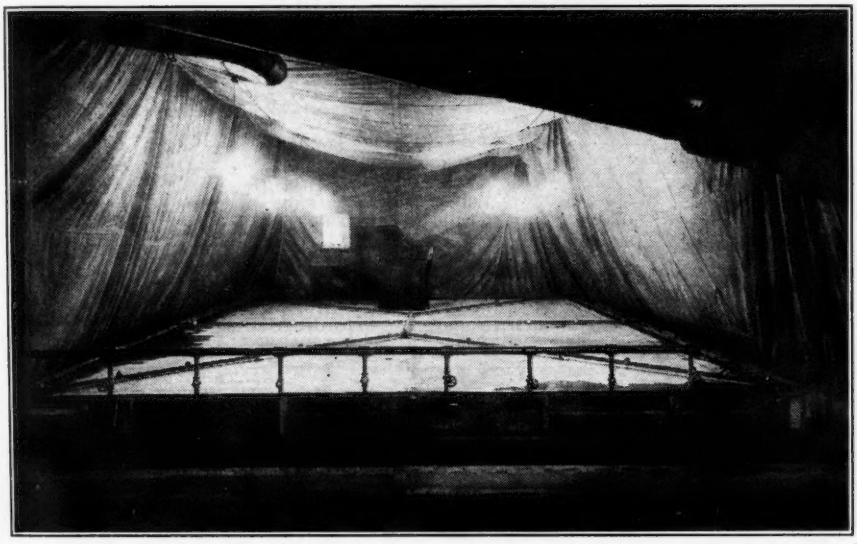


FIG. 1.—GENERAL VIEW OF CONCRETE TEST SLAB SHOWING TENT COVERING AND MEANS OF SATURATING SUB-GRADE.

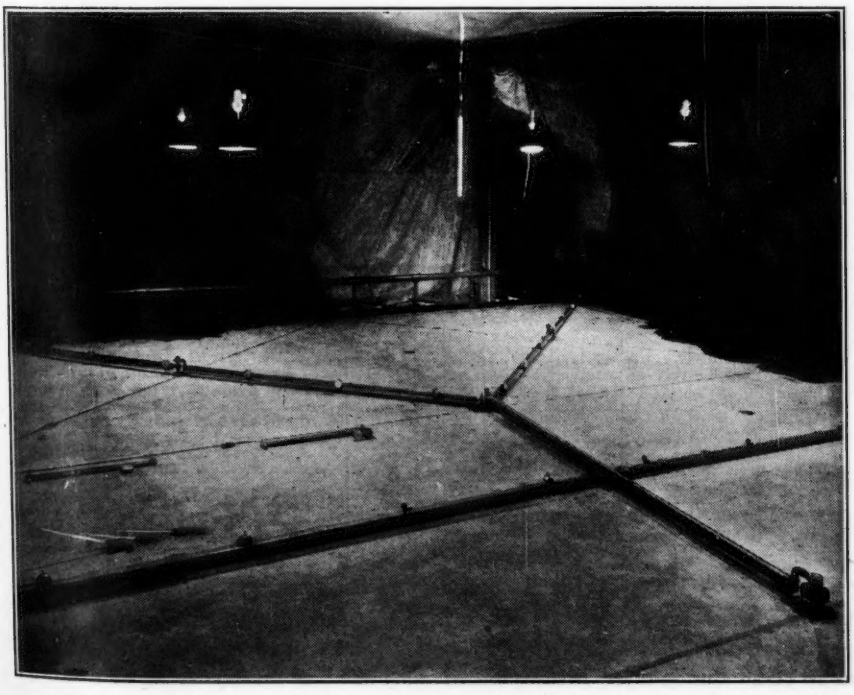


FIG. 2.—DETAILS OF CONCRETE TEST SLAB AND MEASURING APPARATUS.

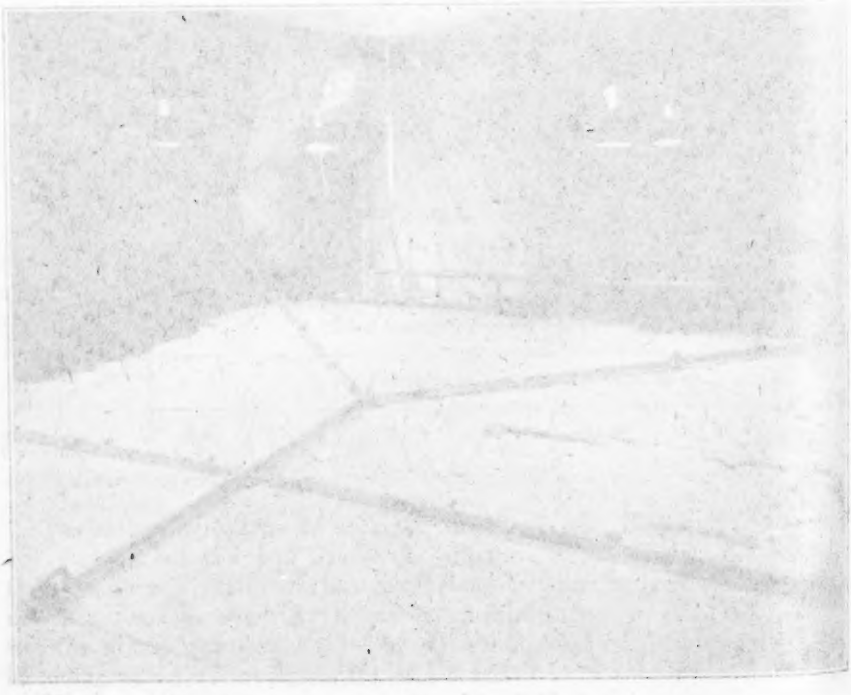


TABLE 3.—TESTS OF CONCRETE.

Slump (4-8 by 12-in. cone) = 1 to 1½ in.
$\frac{W}{C}$ = 0.809 for a 1 : 1½ : 3 mix.
$\frac{W}{C}$ = 0.985 for a 1 : 2 : 3½ mix.
Specific gravity = 2.68.
Density = 0.896.
Percentage of voids = 10.4.
Percentage of absorption by weight = 4.29.

	Average Weights of Both Concretes, in Pounds per Cubic Foot.		
	Oven-dried to constant weight.	Immersed in water to constant weight.	Air-dried in laboratory for 135 days.
Unit weight, in pounds per cubic foot.....	149.89	156.32	151.89

Expansion and Contraction of Cements.—The changes in length of six brands of cement and the concrete made from certain of the brands were measured using Berry extensometers. The specimens were 2 by 2 by 24 in. for neat cement and 4 by 7 in. by 4 ft. 0 in. for concrete. Measurements began two days after moulding with previous moist-chamber storage. The results are shown in Table 4 and in Figs. 3, 4, and 5.

TABLE 4.—EXPANSION AND CONTRACTION OF NEAT CEMENTS AND CONCRETES.

Brand.	A.	B.	C.	D.	E.	F.	Average of A and D.
NEAT CEMENT:							
Percentage of H_2O for normal consistency.....	24.00	24.00	22.00	23.00	23.00	25.00	.....
Percentage retained in 200-mesh sieve.	17.53	22.86	20.38	23.90	16.24	19.14	.....
Percentage of expansion in water, 10 days.....	+0.056	+0.044	+0.040	+0.036	+0.034	+0.030	+0.048
Percentage of contraction in air, 90 days (subsequent to immersion)....	−0.052	−0.062	−0.080	−0.094	−0.114	−0.142	−0.073
Total percentage of change.....	0.108	0.106	0.120	0.130	0.148	0.172	0.121
Net percentage of change.....	+0.004	−0.018	−0.040	−0.058	−0.080	−0.112	−0.025
CONCRETE:							
Gravel concrete, 1 : 2 : 3.5 :							
40 days in water.....	.....	.....	.....	.....	.....	+0.005	.....
90 days in air.....	.....	.....	.....	.....	.....	−0.035	.....
40 days in water, 90 days in air, 20 days in oven.....	.....	.....	.....	.....	.....	−0.040	.....
40 days in water, 90 days in air, 30 days in oven.....	.....	.....	.....	.....	.....	−0.0500	.....
Gravel concrete, 1 : 1.5 : 3 :							
40 days in water.....	.....	.....	.....	.....	.....	.....	+0.0050
90 days in air.....	.....	.....	.....	.....	.....	.....	−0.0150
40 days in water, 90 days in air, 20 days in oven.....	.....	.....	.....	.....	.....	.....	−0.0200
40 days in water, 90 days in air, 30 days in oven.....	.....	.....	.....	.....	.....	.....	−0.0225

If the measurements had begun at the time the specimens were moulded, the comparisons might have been different. (See Appendix II.) A comparison of the basic water content and the voids in the cement paste at this basic water content would no doubt throw light on these differences in the changes of

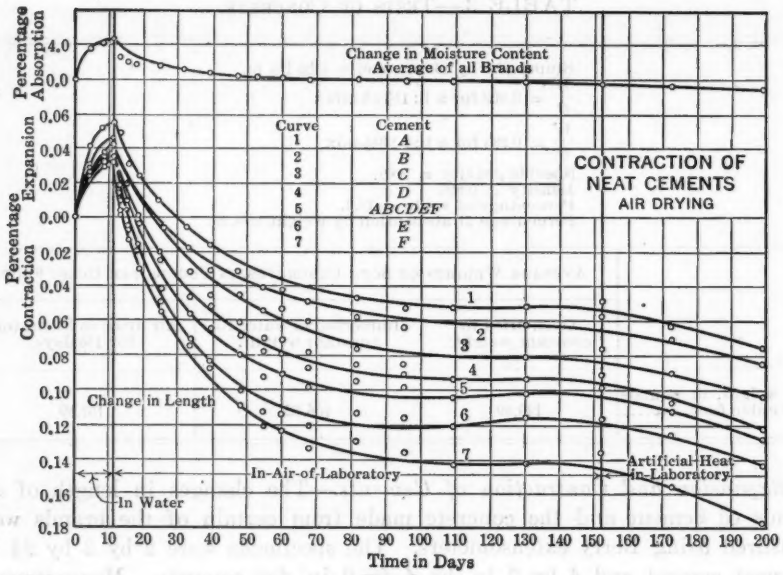


FIG. 3.

length, in the quantity of water required for standard consistency, and in the fineness or percentage retained on the 200-mesh screen as noted in Table 4. The basic water content has been defined by A. N. Talbot, Past-President, Am. Soc. C. E., as the percentage of water at which the voids are a minimum.

It appears that those cements which expand most in water, subsequently contract least in air. The neat cement prisms expanded in water nearly ten

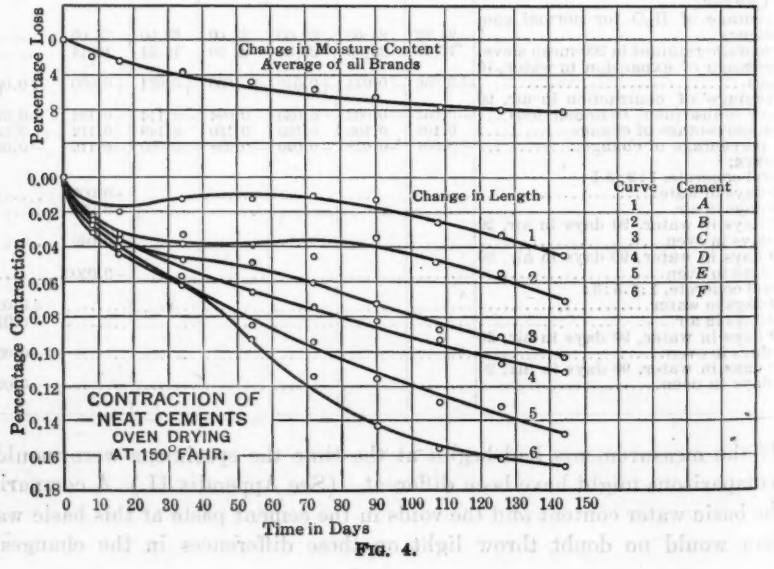


FIG. 4.

times as much as the concrete beams; in air, they contracted nearly five times as much as the concrete.

Expansion Due to Temperature.—The coefficient of temperature expansion of two concretes was measured, with the results shown in Fig. 6. The coefficient varies in amount depending on the temperature, ranging from 0.0000040 per 1° Fahr. to 0.0000065 at a temperature of 150° Fahr. The specimens were dried in an oven previous to testing. In Fig. 6 is shown the thermal coefficient of expansion of several concretes. The temperature of the concrete was obtained from blank beams in which were thermometer wells, consisting of steel pipes filled with a light paraffin oil. The thermometers were graduated to one-fifth of a degree. Reading from the left, the chart covers: (1)

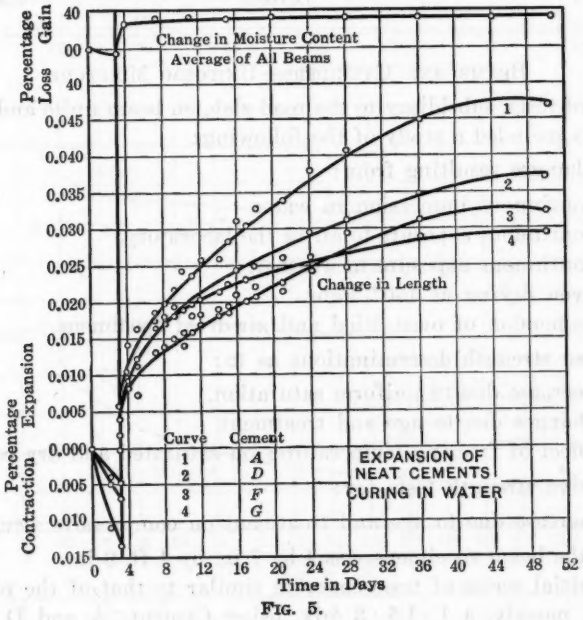


FIG. 5.

Three beams, 6 in. by 8 in. by 4 ft. 0 in., 1 : 1½ : 3 mix, age, 2 months, cured under wet burlap during 30 days, and dried in the oven at 150° Fahr. for 21 days. The beams were taken from the oven and readings taken at intervals of 20° Fahr. as the temperature dropped. Four cycles were read on as many days; (2) two beams, 7 in. by 4 in. by 4 ft. 0 in., 1 : 2 : 3 mix, age, 2 months, kept immersed in water the temperature of which was varied and held constant 2 hours before observation; (3) three beams, 4 in. by 7 in. by 4 ft. 0 in., 1 : 2 : 3½ mix, age, 9 months, cured under wet burlap for 14 days, oven-dried for 1 month, and air-dried for 7½ months; the beams were moved from the warm laboratory air to the cold air of a shed; and (4) two beams, 4 in. by 6 in. by 4 ft. 0 in., 1 : 2 : 3 mix, age, 2 months, cured under wet burlap for 14 days, in air, 6 weeks.

These curves indicate that the variation of coefficient of thermal expansion varies with the temperature range under observation. The thermal coefficient of expansion for the several brands of cement tested neat was as given in Table 5.

TABLE 5.

Brand.	Age, 4 months Dry in air Range, 50°–73° Fahr.	Age, 2 months Under water Range, 52°–90° Fahr.
1	0.0000096	0·0000094
2	0.0000094	.....
3	0.0000092	0.0000087
4	0.0000090	.....
5	0.0000089	... .
6	0.0000083	.....
7	0.0000085	0.0000085

Beams and Cylinders—Uniform Moisture

A series of tests, subsidiary to the road slab, on beam units and compressive cylinders has included a study of the following:

Length changes resulting from:

1.—Continuous immersion in water.
2.—Continuous exposure to air in the laboratory.
3.—Continuous exposure to weather.
4.—Oven drying at 150° Fahr.
5.—Immersion of oven-dried and air-dried specimens.

Transverse strength determinations as to:

1.—Decrease due to uniform saturation.
2.—Changes due to age and treatment.
3.—Effect of freezing temperatures on saturated and dry concrete.

Compressive strength tests for:

1.—Increase due to age and treatment on compressive strength.

The size of the beam specimens was 4 by 7 in. by 4 ft. 0 in.

In the initial series of tests concrete similar to that of the road slab was investigated, namely, a 1 : 1.5 : 3 mix, using Cements A and D. In a later series of tests, Cement F was used, the mix being 1 : 2 : 3.5.

Length Changes of Beams.—Measurements of changes in length of the beams due to moisture were begun two days after moulding. A 20-in. Berry strain-gauge, used in the measurements, was compared to a standard Invar steel bar, maintained at a constant temperature. Six gauge lines were set in each beam, three on the top and three on the bottom. The results are the average of measurements on at least four beams. Corrections for the influence of temperature were made from observations of the temperature of two auxiliary beams, the thermal coefficient of which was previously measured.

Figs. 7 and 8 show the percentage changes in moisture content and the corresponding change in unit length of the concrete. The 1 : 2 : 3.5 concrete, Cement F (Fig. 7), expanded 0.0050% after a continuous curing under saturated burlap for 40 days and contracted 0.0035% after 90 days in air. The

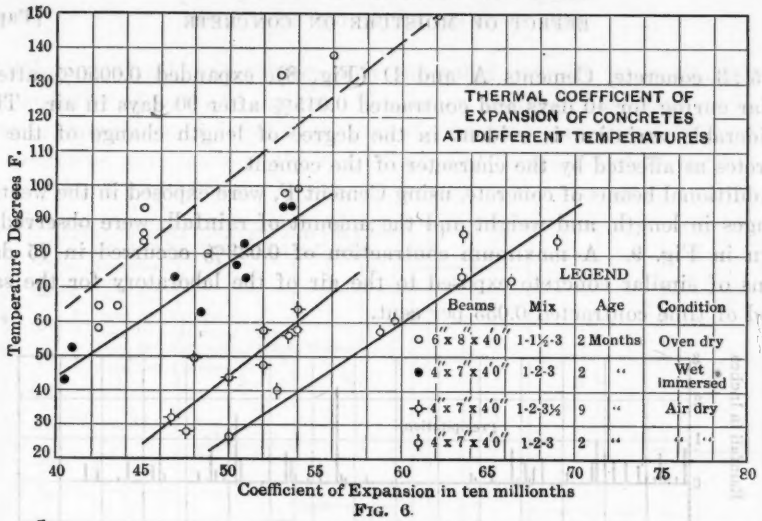

THERMAL COEFFICIENT OF EXPANSION OF CONCRETES AT DIFFERENT TEMPERATURES
Temperature Degrees F.
Coefficient of Expansion in ten millionths
LEGEND
Beams | Mix | Age | Condition
6" x 8" x 40" | 1-1½-3 | 2 Months | Oven dry
4" x 7" x 40" | 1-2-3 | 2 " | Wet Immersed
4" x 7" x 40" | 1-2-3½ | 9 " | Air dry
4" x 7" x 40" | 1-2-3 | 2 " | " "

FIG. 6.

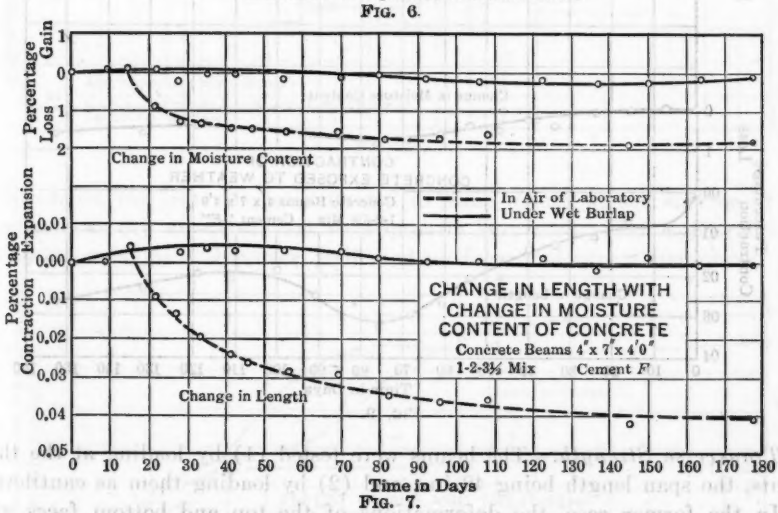


FIG. 7.

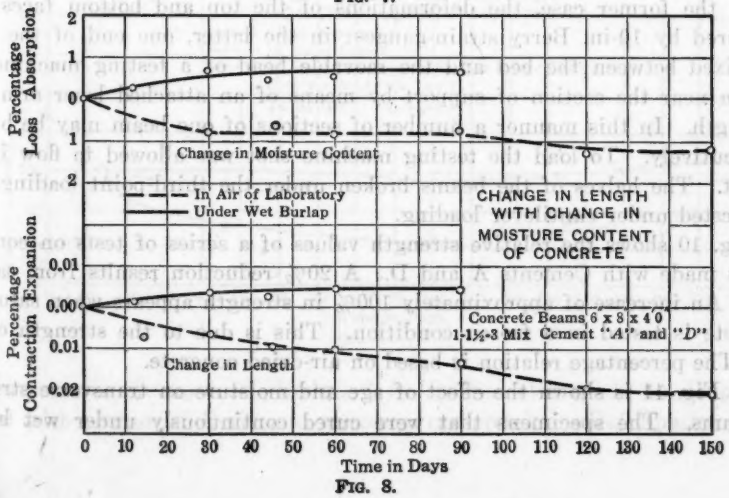

Percentage Loss Absorption
Change in Moisture Content
In Air of Laboratory
Under Wet Burlap
CHANGE IN LENGTH WITH CHANGE IN MOISTURE CONTENT OF CONCRETE
Percentage Contraction Expansion
Concrete Beams 6 x 8 x 40
1-1½-3 Mix Cement "A" and "D"
Change in Length
Time in Days

FIG. 8.

1 : 1.5 : 3 concrete, Cements A and D (Fig. 8), expanded 0.0050% after a similar curing for 40 days and contracted 0.015% after 90 days in air. Thus, considerable variation is evident in the degree of length change of the two concretes as affected by the character of the cement.

Additional beams of concrete, using Cement F, were exposed in the weather. Changes in length, and weight and the amount of rainfall, were observed, as shown in Fig. 9. A maximum contraction of 0.033% occurred in 75 days. Beams of similar concrete exposed to the air of the laboratory for the same period of time contracted 0.033 per cent.

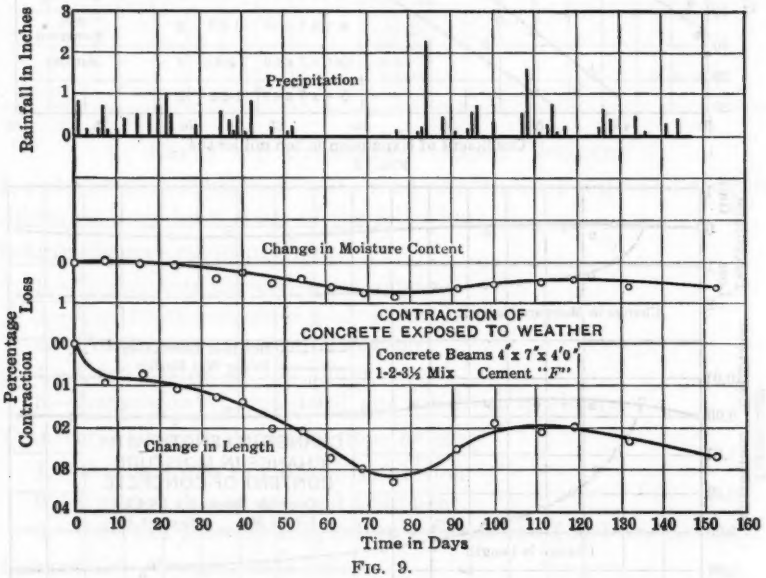


FIG. 9.

Transverse Strength.—The beams were tested (1) by loading at the third points, the span length being 42 in.; and (2) by loading them as cantilevers. In the former case, the deformations of the top and bottom faces were measured by 10-in. Berry strain-gauges; in the latter, one end of the beam was fixed between the bed and the movable head of a testing machine and broken near the section of support by means of an attached lever arm 5 ft. in length. In this manner a number of sections of one beam may be broken consecutively. To load the testing machine shot was allowed to flow into a bucket. The halves of the beams broken under the third-point loading were also tested under cantilever loading.

Fig. 10 shows the relative strength values of a series of tests on concrete beams made with Cements A and D. A 20% reduction results from saturation. An increase of approximately 100% in strength appears when saturated concrete is tested in a frozen condition. This is due to the strength of the ice. The percentage relation is based on air-dried concrete.

In Fig. 11 is shown the effect of age and moisture on transverse strength of beams. The specimens that were cured continuously under wet burlap

and those air-dried, but subsequently saturated, contain approximately the same quantity of water by weight. The latter, however, are consistently 19% lower in strength on a direct basis than the former at an age of 90 days. All the specimens were made at the same time, and then exposed to varying conditions. Each plotted point in Fig. 11 represents the average of twelve tests.

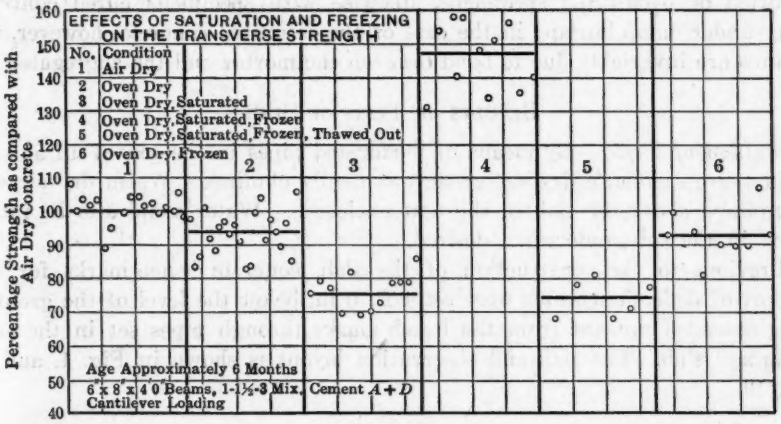

EFFECTS OF SATURATION AND FREEZING ON THE TRANSVERSE STRENGTH
No. Condition
1 Air Dry
2 Oven Dry
3 Oven Dry, Saturated
4 Oven Dry, Saturated, Frozen
5 Oven Dry, Saturated, Frozen, Thawed Out
6 Oven Dry, Frozen
Percentage Strength as compared with Air Dry Concrete
Age Approximately 6 Months
6" x 8" x 4'0" Beams, 1-1½-3 Mix, Cement A + D
Cantilever Loading

FIG. 10.

No doubt the water is concentrated to some extent at the surface of the samples that are air-dried, but subsequently saturated. The appearance of the broken specimens, however, indicated uniform moisture distribution.

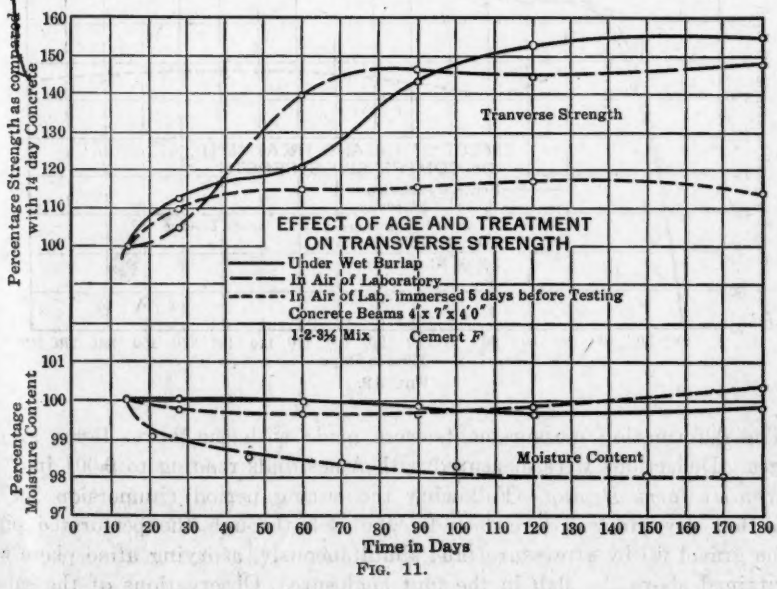

Percentage Strength as compared with 14 day Concrete
Tranverse Strength
EFFECT OF AGE AND TREATMENT ON TRANSVERSE STRENGTH
Under Wet Burlap
In Air of Laboratory
In Air of Lab. immersed 5 days before Testing
Concrete Beams 4" x 7" x 4'0"
1-2-3½ Mix Cement F
Percentage Moisture Content
Moisture Content
Time in Days

FIG. 11.

Compressive Strength.—Cylinders 6 in. in diameter by 12 in. long were capped with plaster of Paris and tested in compression. Deformations were

measured up to about one-half the ultimate strength by means of a ring compressometer, with the results shown in Fig. 12, which checked the findings in the case of the beams. Each plotted point represents the average of three tests.

Aggregate failures occur with consistent regularity in the case of the air-dried or oven-dried specimens, likewise with specimens cured continuously under damp burlap; in the case of the saturated concrete, however, the failures are invariably due to bond between the mortar and the aggregate.

Results of Tests of Slab

Method of Tests.—By means of perforated pipes in the gravel fill and an air-pressure system, a dry sub-grade was finally obtained. Warm dry air was maintained above the slab in the tent enclosure. Water could also be introduced in the sub-grade when desired.

Previous to the construction of the slab, concrete bench-marks for the support of deflection beams were set 4 ft. 0 in. below the level of the ground. Rods extended upward from the bench-marks through pipes set in the sub-grade and slab. The slab and observation layout is shown in Fig. 1, and in Fig. 13.

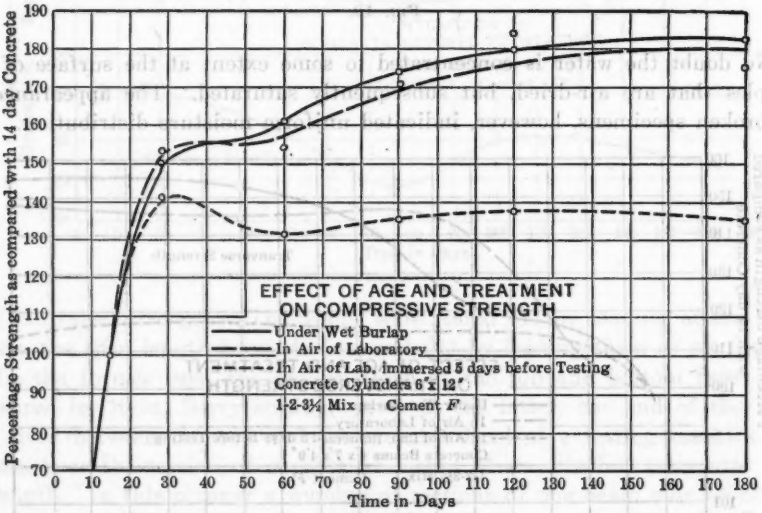


Fig. 12.

The deformation measurements were made with the 20-in. Berry strain-gauges. Deflections were measured with Ames dials reading to 0.001 in.

Non-Uniform Drying.—Following the curing period (immersion for 28 days) hot dry air was forced under the slab through the perforated pipes in the gravel fill by a pressure fan; simultaneously, a drying atmosphere was maintained above the slab in the tent enclosure. Observations of the subsequent deformations and deflections were taken at weekly intervals. (See Figs. 14, 15, 16, and 17.)

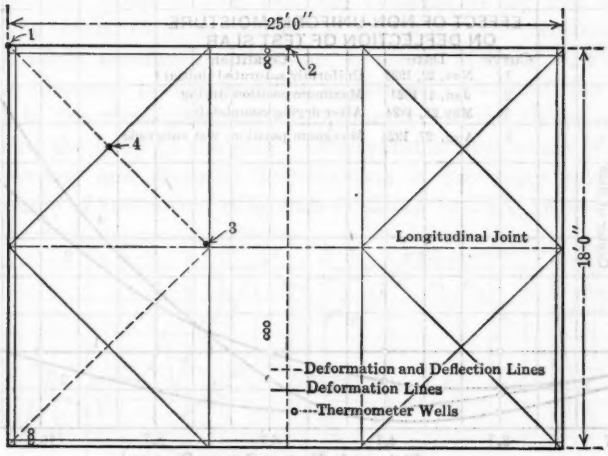

25'-0"
18'-0"
1
2
3
4
Longitudinal Joint
Deformation and Deflection Lines
Deformation Lines
Thermometer Wells

FIG. 13.

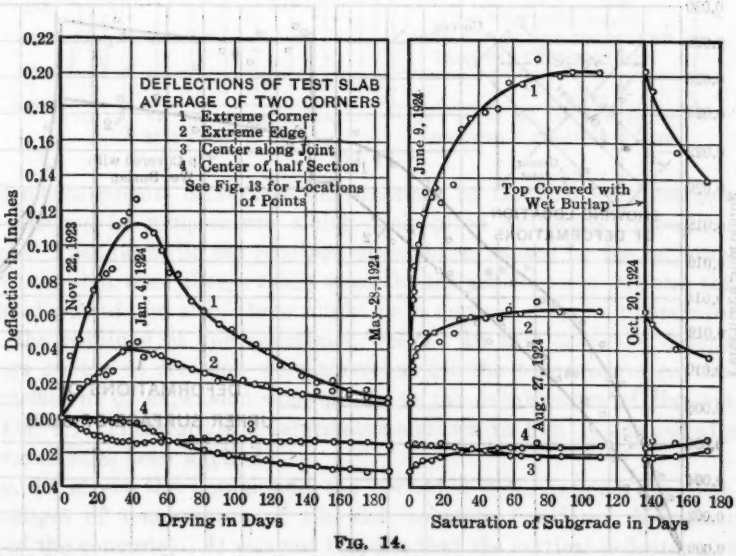

DEFLECTIONS OF TEST SLAB
AVERAGE OF TWO CORNERS
1 Extreme Corner
2 Extreme Edge
3 Center along Joint
4 Center of half Section
See Fig. 13 for Locations of Points
Deflection in Inches
Nov. 22, 1923
Jan. 4, 1924
May 23, 1924
Drying in Days
June 9, 1924
Top Covered with Wet Burlap
Aug. 27, 1924
Oct. 20, 1924
Saturation of Subgrade in Days

FIG. 14.

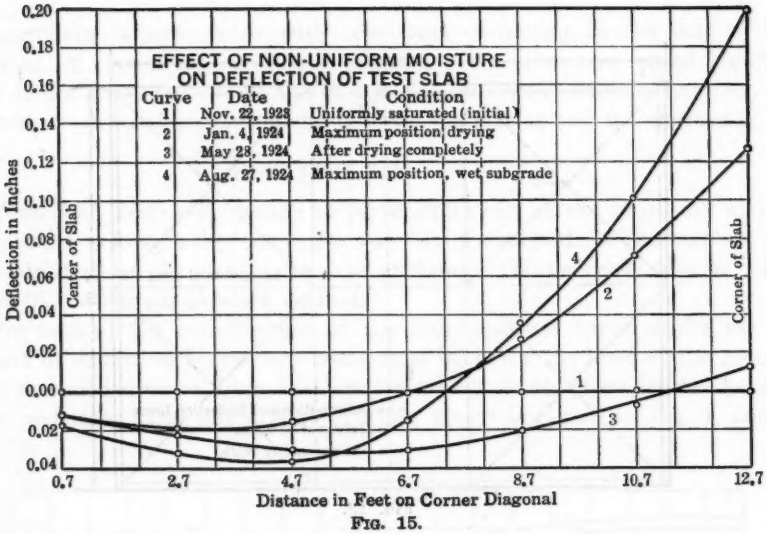

EFFECT OF NON-UNIFORM MOISTURE ON DEFLECTION OF TEST SLAB
Curve Date Condition
1 Nov. 22, 1923 Uniformly saturated (initial)
2 Jan. 4, 1924 Maximum position, drying
3 May 23, 1924 After drying completely
4 Aug. 27, 1924 Maximum position, wet subgrade
Deflection in Inches
Center of Slab
Corner of Slab
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.02
0.04
0.7
2.7
4.7
6.7
8.7
10.7
12.7
Distance in Feet on Corner Diagonal

FIG. 15.

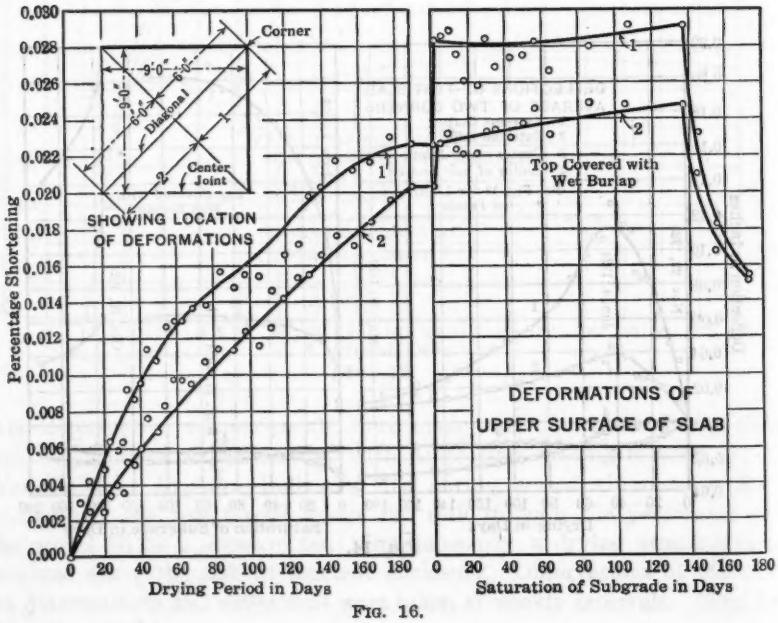

Percentage Shortening
0.030
0.028
0.026
0.024
0.022
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
Corner
9'-0"
6'-0"
Diagonal
Center Joint
SHOWING LOCATION OF DEFORMATIONS
0 20 40 60 80 100 120 140 160 180
Drying Period in Days
Top Covered with Wet Burlap
DEFORMATIONS OF UPPER SURFACE OF SLAB
0 20 40 60 80 100 120 140 160 180
Saturation of Subgrade in Days

FIG. 16.

The more pronounced shrinkage occurring in the upper fibers was manifested by the fact that the edges and corners gradually curled up. A maximum uplift of 0.04 in. for the unbroken edges (at Point 2, Fig. 14), and 0.12 in. for the corners (at Point 1, Fig. 14), was attained at the end of 40 days. The subsequent return to a non-warped or uniformly dry condition required 5 months. A slight permanent distortion, as shown at Point 3, Fig. 15, representing the diagonal profile previous to the saturation of the sub-grade, is attributed to the more pronounced contraction of the richer or troweled surface than of the body of the slab. Observations were made of the longitudinal, transverse, and diagonal deformations in the upper surface of the slab. An average of two corner diagonals is shown in Figs. 16 and 17.

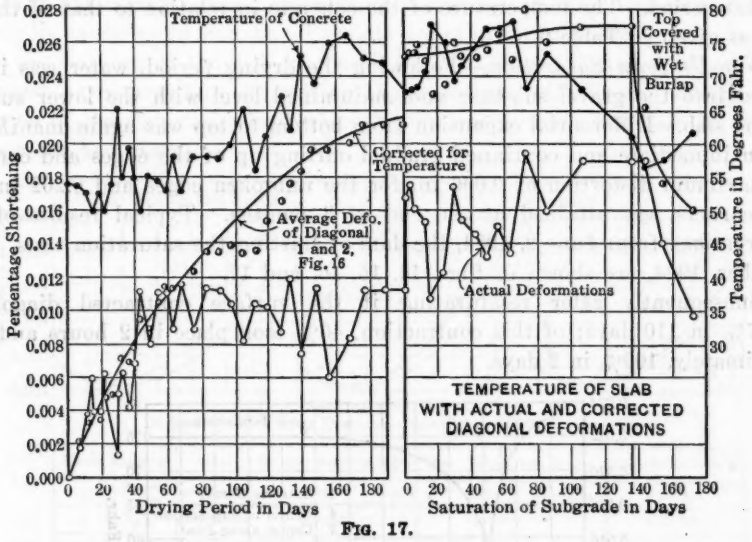

Temperature of Concrete
Top Covered with Wet Burlap
Corrected for Temperature
Average Defo. of Diagonal 1 and 2, Fig. 16
Actual Deformations
TEMPERATURE OF SLAB WITH ACTUAL AND CORRECTED DIAGONAL DEFORMATIONS
Percentage Shortening
Temperature in Degrees Fahr.
Drying Period in Days
Saturation of Subgrade in Days

FIG. 17.

All measurements of surface deformations of the slab were corrected for these changes in temperature which took place uniformly throughout the concrete. That is, while the readings of warping, caused by the moisture gradient in the slab, were always taken when the temperature was uniform throughout the depth of the slab, there might be a general drop in temperature between the readings of two successive weeks. In this case, the deformation readings on top of the slab were corrected for the temperature on the basis of a coefficient of expansion appropriate to the temperature of the concrete. (See Fig. 6.) Therefore, the deformations shown in Fig. 16 are net after the corrections have been applied.

Fig. 17 shows the actual and the corrected deformations, together with the changes of temperature of the slab concrete (uniform throughout the depth of the concrete). It was not thought that the vertical deflections caused by the moisture gradient need be changed on account of these uniform changes.

The total diagonal contraction due to the moisture gradient between the condition of saturation (November 22, 1923) and that of completely dried concrete (May 28, 1924) was 0.021 per cent. This value, like all others, has

been corrected for uniform temperature changes. Beams of 1 : 1.5 : 3 concrete contracted 0.020% in 160 days. The friction of the sub-grade apparently did not restrain these movements.

The fact that some of the points fall off the curve in Fig. 14 is attributed to a slight effect of temperature in the warping of the slab. In so far as possible, the observations were taken at times when the temperatures were uniform from the top to the bottom of the concrete.

Effect of Daily Variations of Temperature.—The effect of daily variations of temperature in the air above the slab (not the outdoor temperature) is shown in Fig. 18. A temperature rise of 40° Fahr. from 8:00 A. M. to 3:00 P. M., warped the corner downward 0.023 in., or 21.0% of the total warping (0.11 in.) at that period. The temperature of the concrete in relation to that of the air was as given in Table 6.

Non-Uniform Saturation.—Following the drying period, water was introduced into the gravel sub-base and maintained level with the lower surface of the slab. Differential expansion from bottom to top was again manifested in an immediate and continued gradual curling up of the edges and corners. A maximum distortion of 0.066 in. for the unbroken edges and 0.202 in. for the corners was attained at the end of 3 months. Typical results of the observations from June 2, 1924, the date of starting the saturation tests, until October, 1924, are shown in Figs. 14, 15, 16, and 17.

Subsequently after resaturating it the surface contracted diagonally 0.007% in 110 days; of this contraction, 46% took place in 2 hours and, approximately, 100% in 2 days.

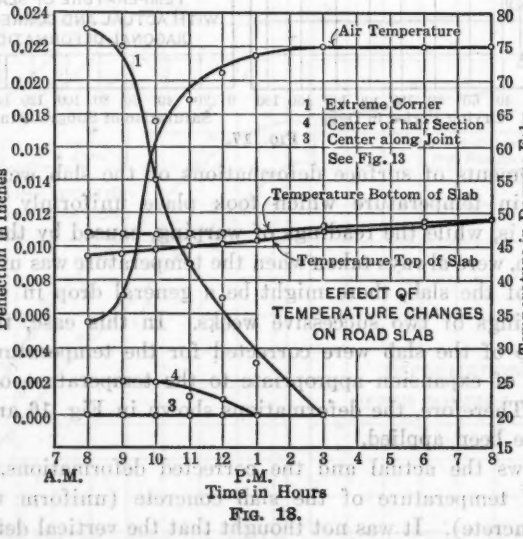


FIG. 18.

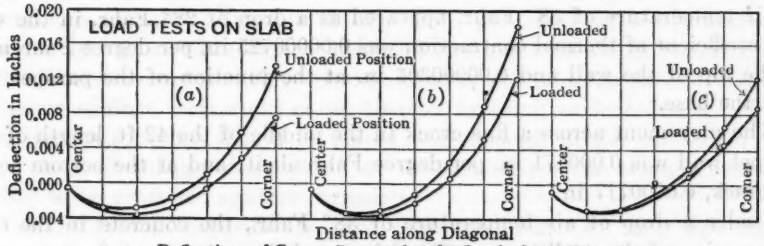
When the slab had reached a static condition with saturated sub-grade (on October 20, 1924), an attempt was made to expand the surface by applying saturated burlap. In 30 days the corner had dropped 0.060 in. to a deflection of 0.140 in.

TABLE 6.—TEMPERATURE VARIATIONS.

Time.	8:00 A.M.	3:00 P.M.	8:00 P.M.
Temperature of air, in degrees Fahrenheit	34	75	75
Temperature of top slab, in degrees Fahrenheit	44.0	47.5	49.0
Temperature of bottom slab, in degrees Fahrenheit	47.0	48	49.0

Load Tests on Slab.—Known loads were applied to one corner of the slab by jacking at three stages of the test: (*a*) On June 14, 1924, during the drying stage; (*b*) on September 23, 1924, during the saturation of the subgrade; and (*c*) on November 14, 1924, when the top had been saturated 25 days with wet burlap. The profiles of the diagonal on these dates for a load of 3 000 lb., is shown in Fig. 19. The data are as given in Table 7.

As the warping of the slab increased (see (*b*), Fig. 19), the point of support must have moved in, increasing the deflection. Curiously enough, the deflection of the slab under load when the top was wet was less than in either of the other two cases.



Deflections of Corner Diagonal under Load of 3000 lb. at Corner

Figure	Condition	Date	Deformation along Corner Diag.	Stress from $S=\frac{MC}{I}$	Mod. Elas. in Tension
a	During Drying	June 14, '24	0.000037" per inch	185.0 lb. per sq. in.	5 000 000
b	Bottom Wet	July 23, '24	0.000035" " "	185.0 " " " "	5 300 000
c	Top Wet	Nov. 14, '24	0.000031" " "	185.0 " " " "	6 000 000

FIG. 19.

TABLE 7.—DEFLECTION OF SLAB DUE TO CORNER LOAD OF 3 000 LB.*

	a.	*b.*	*c.*
Corner level, in inches:			
Before load	+0.0131	+0.0183	+0.0124
With load	+0.0077	+0.0120	+0.0091
Deflection due to load	0.0054	0.0063	0.0033
Set due to load, after 5 min.	+0.008	+0.009	+0.008
Percentage of elongation under stress (in distance of 48 in. adjacent to the corner):			
Diagonal	0.0037	0.0035	0.0031
Edges	0.0025	0.0023	0.0017

* Sign + indicates that the elevation is above the original level of the surface of the slab after casting.

Reversed Stresses on Saturated Mortar.—The fatigue limit on 1 : 2 mortar tested dry at an age of 6 to 12 months was approximately 55% of the once applied load, as reported* by Professor R. B. Crepps, of Purdue University.

* *Proceedings*, Am. Soc. for Testing Materials, 1923.

Recently, similar beams, 18 months old, were tested in the fatigue machine, while saturated, with the following results:

The saturated beams showed 89% of the static strength of the dry beams.

Beam No. 162 failed at 200 reversals under a load equal to 55% of the once applied load on saturated concrete; duration of test, ½ hour.

Beam No. 161 failed at 8 400 reversals at 50% load; duration of test, ½ day.

Beam No. 165 failed at 17 200 reversals of 50%; duration of test, 1¼ days.

Beam No. 164 failed at 71 700 reversals of 40%; duration of test, 5 days.

These tests are being continued. It would appear that a little less than 55% of the static strength of dry concrete should be the working strength of the concrete that has been saturated 8 days.

Observations on a Concrete Stadium.—Gauge points are set at a number of locations both in the open deck and in the bank revetment of the new Ross-Ade Stadium of Purdue University. The changes of length consequent upon moisture and temperature variations are under observation.

A parapet wall, 6 in. thick, reinforced at center of thickness with 0.3% of reinforcement each way, is integral with a heavy foundation wall. A drop of air temperature of 38° Fahr. appeared as a drop of 28° Fahr. in the wall. The coefficient of thermal contraction was 0.00000725 in. per degree Fahrenheit at the top of the wall and 0.00000305 in. at the junction of the parapet wall with the base.

The movement across a fine crack in the middle of the 42-ft. length of this parapet wall was 0.000471 in. per degree Fahrenheit; and at the bottom across the crack, 0.0000717 in.

Under a drop of air temperature of 38° Fahr., the concrete in the open deck section of the stadium was 37° Fahr.; and the concrete of the revetment, 24° Fahr. The coefficient of thermal expansion of the open deck was 0.00000590 and that of the revetment, 0.00000492.

The effects of a rainfall, followed by a drop in temperature of 10° Fahr., balanced each other and no change of length was recorded in the deck, corresponding to a thermal coefficient of 0.0000050 and a swelling of 0.005 per cent.

Conclusions and Application

As a result of the studies described in this paper and its appendices the writer has reached the following conclusions:

1.—The strength of concrete, like that of wood, varies with its moisture content. Although the law relating to moisture content and to strength was not determined throughout various ranges of moisture content, it appears that saturated concrete will have 80 to 85% the strength of dry concrete.

2.—The thermal coefficient of expansion of concrete varies with the temperature of the concrete and ranges from 0.0000040 at 65° to 0.0000060 at 140°.

3.—Concrete expands when immersed in water and contracts on drying. The degree of change of length varies with the characteristics of the brand of cement, with the richness of the mix, with the size of specimen, and with the conditions of exposure. Measurements begun after the initial hardening of the cement show that concrete may expand 0.01% due to the absorption of moisture, and may contract 0.06% when exposed to dry air. These

changes continue. To these values should be added the changes in length during the initial setting of the cement.

4.—Concrete road slabs warp upward at the corners and at the edges when the surface becomes dry, and also when the bottom absorbs moisture from the sub-grade. Drying the top surface of the slab under observation deflected the corners upward 0.02 in. When the bottom of the slab was saturated from a water-filled sub-grade the upward corner deflection reached 0.20 in.

5.—This curling upward of the corners of the road slab presents a cantilever beam to the load of a passing truck. The results of the tests indicate the presence of an initial stress in the surface of the road slab arising from the warping.

6.—A combination of shrinkage from drying and from a fall in temperature will produce maximum shrinkage strains. A combination of a drop in temperature and a rainfall may retain the concrete at its previous length. The friction of a road slab on its sub-grade is an element favoring the production of cracks.

7.—To be durable, concrete structures should be designed for the least favorable conditions. Stresses arising from the effect of temperature and moisture as well as those due to dead and live loads should be considered.

8.—Without careful curing concrete masses will undergo excessive surface shrinkage against their rigid cores, thereby favoring surface cracks. Therefore, steel reinforcing should be placed near enough to the surface to withstand these shrinkage strains, and at the same time far enough below the surface to be protected against corrosion.

9.—The foreign experiments cited show the benefit of early and careful curing of concrete in reducing final shrinkage. The greater part of the shrinkage of mortar specimens took place in the first ten hours. These foreign experiments also show the greatly increased shrinkage of mortar mixed with an excess of water.

10.—Since the results of measurements of expansion vary with several factors, such as the size of specimen, the time of initial measurement, and the exposure, the method of such tests should be standardized.

The writer believes that the following are the requirements for concrete structures exposed to the weather:

(*a*) A Portland cement of normal volume constancy and a clean, well graded aggregate.

(*b*) An impervious concrete of proportions not less than 1 : 2 : 4.

(*c*) A time of mixing of not less than 1 min. and preferably 1½ min. for the production of uniform concrete.

(*d*) A concrete mixed with a minimum quantity of water appropriate to the work at hand.

(*e*) Careful slicing of this dry concrete against the face of the forms so that the reinforcing steel may not be exposed nor the surface require patching.

(*f*) Early curing begun just after the initial set and continued for a time depending on local conditions.

(*g*) Design of reinforcing steel and contraction or expansion joints to prevent cracking and the entrance of water.

APPENDIX I

Study of Warped Beams

Description of Tests.—The beam specimens were dried to constant weight; some were then entirely immersed in water and others immersed to only a fraction of their depth. The changes in weight, length, and strength were determined for the different conditions. Five separate series of such experiments were conducted, varying the proportions of the mix, the brand of cement, the extent and nature of drying, and the depth of partial saturation. The results are shown in Table 8.

Results of Tests.—By reference to Table 8, a comparison of beams uniformly saturated, shows that the expansion in water varies from 0.014 to 0.021%, with an average of 0.018 per cent. These beams were immersed for 5 days subsequent to the initial drying. The 1 : 2 : 3.5 concrete made with Cement F when air-dried for 2½ months contracted 0.041 per cent.

The 1 : 1.5 : 3 concrete, made with Cements A and D mixed, after conditioning by 30 days, curing under wet burlap followed by complete oven-drying, contracted 0.022 per cent.

The reduction in strength from completely dried concrete to uniformly saturated concrete in the five cases ranges from 11.7 to 22.2%, an average of 15.4 per cent.

Certain beams were warped by saturation from the bottom upward to increasing heights (see Table 8), as determined by visual observations of the broken beams and by weighing.

Contractions from 0.0016 to 0.0065% were developed in the dry face, and expansions from 0.015 to 0.032% at the wet face of the warped beams. When these warped beams were broken with the contracted dry side in tension, an increase from 9.5 to 27.0% in strength over the entirely dry beam was indicated, depending on the amount of initial contraction.

When saturation had proceeded to a greater height in the beams (approximately 2 in. from the top), the area of dry concrete became too small to hold back the expansion of the wet area, and, consequently, the dry face was actually elongated by the force of the expanding face. When the expanded dry face was tested in tension, the beams were only 80.7 to 96.5% as strong as the uniformly dry beams; when turned with the wet side in tension, the percentage was 71.3 to 83.5. The complete data are given in Table 8.

The writer accounts for this increase in strength of warped dry faces when they have been shortened and the decrease in strength when they have been lengthened due to the absorption of moisture on the opposite face by the presence of an initial compression in the former and of an initial tension in the latter case. However, an analysis of moduli of elasticity and the deformations of the top and bottom face of the beams tested under the one-third point loading, fails to show any substantial difference between the extensibility, at rupture or 50% of rupture, of the beams with the dry face either shortened or lengthened by warping. The neutral axis in all these loaded warped beams is nearer the compression than the tension face (wet or dry) at 50% of rupture and also at rupture. The maximum extensibility in tension was from 0.015

TABLE 8.—MODULUS OF RUPTURE DATA OF WARPED BEAMS.

SERIES NO. 1. 6 IN. BY 8 IN. BY 4 FT. 0 IN. BEAMS. 1 : 1.5 : 3 MIX. CEMENTS A AND D. AGE, 4 MONTHS. OVEN DRY.

Number of beams.	Initial contraction, in percentage.	Condition at time of test.	Visual height of water, in inches.	Percentage Deformation at Time of Test.		Face loaded in tension.	Modulus Rupture Cantilever Loading.			Modulus Rupture One-Third Point Loading.			Modulus rupture percentage of grand average
				Wet face.	Dry face.		Number of values.	Numerical values.	Percentage of reference values.	Number of values.	Numerical values.	Percentage of reference values.	
5	0.022	Dry	....	.....	.....	....	20	720	100	....	....	....	100
2	0.022	Saturated	....	+0.020	.....	....	10	616	85	....	....	....	85
5	0.022	Saturated to 2 in. depth	3	+0.019	−0.0016	Dry	19	789	109	....	....	....	109
5	0.022	Saturated to 2 in. depth	3	+0.019	−0.0016	Wet	19	602	83	....	....	....	83

SERIES NO. 2. 7 IN. BY 4 IN. BY 4 FT. 0 IN. BEAMS. 1 : 2 : 3.5 MIX. CEMENT F. AGE, 3 MONTHS. AIR DRY.

3	0.041	Dry	....	.....	.....	....	8	839	100	3	738	100	100
3	0.041	Saturated	....	+0.017	.....	....	8	672	80	2	506	68	77
4	0.041	Saturated to 2½ in. depth	3½	+0.024	+0.0035	Dry	12	750	89	4	614	83	87
4	0.041	Saturated to 2½ in. depth	3½	+0.024	+0.0035	Wet	12	618	73	4	472	64	71

SERIES NO. 3. 7 IN. BY 4 IN. BY 4 FT. 0 IN. BEAMS. 1 : 2 : 3.5 MIX. CEMENT F. AGE, 3 MONTHS. OVEN DRY.

8	0.049	Dry	....	.....	.....	....	20	780	100	7	652	100	100
7	0.049	Saturated	....	+0.018	.....	....	19	671	85	5	544	83	85
3	0.049	Saturated to 2½ in. depth	4	+0.021	+0.016	Dry	10	637	81	3	511	78	80
3	0.049	Saturated to 2½ in. depth	4	+0.021	+0.016	Wet	10	609	78	3	478	72	76

TABLE 8.—(*Continued.*)

SERIES No. 4. 7 IN. BY 4 IN. BY 4 FT. 0 IN. BEAMS. 1 : 2 : 3.5 MIX. CEMENT F. AGE, 7 MONTHS. OVEN DRY, 3 MONTHS. AIR DRY, 4 MONTHS.

Number of beams.	Initial contraction, in percentage.	Condition at time of test.	Visual height of water, in inches.	Percentage Deformation at Time of Test.		Face loaded in tension.	Modulus Rupture Cantilever Loading.			Modulus Rupture One-Third Point Loading.			Modulus rupture percentage of grand average.
				Wet face.	Dry face.		Number of values.	Numerical values.	Percentage of reference values.	Number of values.	Numerical values.	Percentage of reference values.	
1	0.037	Dry	....	.....	.....	....	4	809	100	1	651	100	100
1	0.041	Saturated	....	+0.014	.....	....	3	699	86	1	553	85	86
1	0.043	Saturated to 1½ in. depth	3½	+0.017	−0.004	Dry	3	961	118	1	742	114	117
2	0.040	Saturated to 2¾ in. depth	4	+0.015	+0.0003	Dry	7	774	95	1	646	99	96
1	0.040	Saturated to 4 in. depth	5	+0.018	+0.0017	Dry	3	670	82	1	565	86	83

SERIES No. 5. 7 IN. BY 4 IN. BY 4 FT. 0 IN. BEAMS. 1 : 2 : 3.5 MIX. CEMENT F. AGE, 7 MONTHS. AIR DRY.

2	0.051	Dry	....	.....	.....	....	6	825	100	2	731	100	100
1	0.047	Saturated	....	+0.021	.....	....	3	733	88	1	633	86	88
1	0.048	Bottom wet	2	+0.020	−0.0065	Dry	3	1066	129	1	884	121	127
2	0.052	Saturated to 1¼ in. depth	2½	+0.027	−0.0048	Dry	6	910	110	2	734	100	107
1	0.054	Saturated to 2½ in. depth	3½	+0.032	+0.0012	Dry	4	714	86	1	651	89	87

to 0.018 per cent. The simultaneous compression was from 0.012 to 0.016 per cent.

To assume an initial stress would presuppose an elastic concrete holding this stress throughout the five days previous to the test, and an unusual distribution of stresses throughout the cross-section. Inasmuch as these initial stresses must balance, it is difficult to reconcile an initial compression in the top with a compression in the saturated bottom. This matter is left open for discussion.

Deformations Throughout Cross-Section.—In order to interpret the deformations occurring in the bottom and top of the road slab, a study was made of similar deformations observed in the warped beam units. The size of these units, 4 in. by 7 in. by 4 ft. 0 in., was chosen to give a thickness equal to that of the road slab. After initial drying, the beams were placed with the bottom in contact with wet burlap and successive observations of deformation and corresponding deflection were taken. Deformations were recorded at seven different depths between two pairs of sections in each beam. The average results for three beams are shown in Fig. 20. During nine days the lower face expanded 0.0152% and the upper face shortened 0.0024 per cent. The data locate the position of the neutral axis of deformations and show the relative deformations occurring throughout the depth of the beam. The height to which the saturation, visually observed, proceeded at the end of nine days was approximately 2⅔ in., or one-third the depth of the beams.

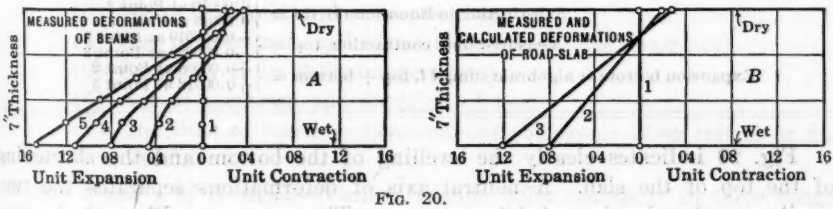


FIG. 20.

If the curve of distortion of a warped beam is assumed to be an arc of a circle, the following formula is applicable to the data:

$$d\,l = \frac{8\,h\,m}{L \cdot L} \qquad (1)$$

in which,

$d\,l$ = algebraic summation of deformations in top and bottom of the beam;

h = depth of beam;

m = deflection;

L = length over which deflection occurs.

In checking any of the measured deflections against the deformations, or *vice versa*, by substitution in Equation (1), it is found that the calculated values (see Table 9) agree closely with the measured values (Fig. 20).

Application of Formula to Data of Road Slab.—Table 9 shows the values of the deformations computed by formula as occurring in the bottom of the

road slab and resulting from flooding the sub-grade, thus saturating the bottom concrete. Here the expansions of the under side of the slab are calculated by substitution of the known measurement of the deflection and deformation of the upper surface in Equation (1). Each step in the calculations is shown.

TABLE 9.

ILLUSTRATION A.

Curve.	Condition.	Measured deflection over 40-in. span.
1	Uniformly dry, Unit contraction 0.0004	0.0000
2	Bottom wet, 24 hours	0.0020
3	" " 48 "	0.0030
4	" " 4 days	0.0041
5	" " 9 "	0.0048

ILLUSTRATION B.

Curve.	Condition.	Measured deflection over 40-in. span.
1	Uniformly dry, Unit contraction 0.0002	0.0000
2	Bottom wet, 11 days (Interior Section)	0.0028
3	" " " (Exterior ")	0.0042

Substituting in Equation (1), $d\,l$ = { 0.00010 at Point 2 ; 0.00015 at Point 3

Measured unit contraction, top = { −0.000019 at Point 2 ; −0.000028 at Point 3

Expansion bottom = algebraic sum, $d\,l$, top + bottom = { +0.00008 at Point 2 ; +0.00012 at Point 3

Fig. 20 indicates clearly the swelling of the bottom and the shortening of the top of the slab. A neutral axis of deformations separates the two, similar to that in the subsidiary beams. The greater swelling of the concrete at the unrestrained edge of the slab, and the less swelling at the interior restrained portions is shown.

The translation of the measured deformations into stresses, and the variation of such stresses throughout the cross-section, is a field of discussion of considerable interest. The corners of the slab are held up against the dead weight of the overhanging cantilever, which has been raised by the swelling of the bottom concrete. What is the state of stress in the top, which has been shortened?

APPENDIX II

REVIEW OF LITERATURE ON EXPANSION AND CONTRACTION OF CEMENTS, MORTARS, AND CONCRETE*

I.—Volume Changes

The earlier measurements of volume changes in concrete cover a wide range as to size and age of specimen, quality of cement, kind of aggregate, richness of mix, duration of exposure, time of initial measurement, etc., and, consequently, a wide range of values. More recently the importance of volume changes occurring during the first ten hours have begun to be appreciated, the underlying influences have begun to be evaluated, the nature of the action understood, and, therefore, a possibility of remedy suggested. The necessity of protecting concrete from volume changes as soon as possible after pouring is evident.

Volume changes are due to: Shrinkage and expansion; temperature changes; and plastic flow under load.

The factors influencing the shrinkage and expansion, in part at least, are:

(1) Composition of cement.
(2) Aggregate (fineness and quality).
(3) Wetness of mix and proportioning.
(4) Size of specimen, and forms (whether absorptive or not).
(5) Exposure (humidity, temperature).
(6) Age of specimen and duration of test.
(7) The time of starting measurement (before or after initial or final set).

(*1*) *Quality of Cement.*—Various brands differ markedly in their volume constancy, depending on chemical composition and fineness.

Tests by the U. S. Bureau of Standards† were made on neat cement and on 1 : 3 mortar cured in water. At thirteen weeks the expansion was: Neat cement, 0.066% (0.057 to 0.120); 1 : 3 mortar, 0.024% (0.005 to 0.012). Using the same cements re-ground, the expansion increased to 0.085% and 0.13, respectively.

Mr. John Grant‡ showed that expansion was increased when cements contained gypsum.

Recent tests at Purdue University show the changes in six brands of cement and in concrete made from certain of the brands. (See Table 4 and Figs. 3 and 4.)

D. A. Abrams, M. Am. Soc. C. E., in 1919,§ in connection with an investigation of the effect of fineness of cement, found no appreciable differences in

* No attempt has been made to discuss the early experiments, such as the thorough investigation of Professor White of the University of Michigan.

† *Proceedings*, Am. Soc. for Testing Materials, Vol. 15, 1915, p. 141.

‡ *Minutes of Proceedings*, Inst. C. E., Vol. LXII, 19 .

§ *Bulletin No. 4*, Structural Materials Laboratory, Lewis Inst., Chicago, Ill.

volume change due to fineness, but he states that the measurements were not precise.

A paper in *Le Ciment* (1923) quotes expansion tests with Le Chatelier apparatus as shown in Table 10.

TABLE 10.

	Residue.		Expansion: Le Chatelier apparatus.
	Sieve 900.	Sieve 4 900.	
Cement A.	3%	28%	6 mm.
	2%	20%	3 "
	1%	16%	1 "
Cement B.	2 %	25%	2 mm.
	1.5%	20%	2 "
	0.5%	14%	½ "

The author remarks that this expansion may be reduced by finer grinding, providing the cement is well burned. Methods such as airing of cement will also lessen expansion. Disaggregation of concrete is attributed to the influence of gypsum, which constituent, expressed as SO_3, varies from 1.75 to 3.00 per cent. Some countries allow only one-half as much SO_3 when the cement is to be used in sea water. Experiments in Germany on concrete exposed to sea water for 10 years are quoted to show that 2.5% of SO_3 is not detrimental either in fresh or salt water. The author believes that the Le Chatelier apparatus for which 6 mm. is specified will detect expansive cements, but will reject cements that are worthy; he recommends a specification of 10 mm. (See, also, tests by Otto Graf, discussed subsequently.)

Dr. H. Nitzsche* measured the volume change of several cements with the Bauschinger apparatus. Mortars approximately 1 : 4 and of consistencies appropriate in reinforced concrete were used. The Bauschinger prisms were conditioned as follows: 2 days in moulds, 7 days in water, 10 days in room temperature, and then dried to constant weight at 50° cent. The length of the "wassergesättigt" prisms in percentage of the dry mortars was, as shown in Table 11, when the cements are listed in order of increasing fineness.

TABLE 11.

Cement.	Percentage volume change in water.
Finest slag cement	0.0275
" " "	0.0204
Finest Portland cement	0.0347
Coarsest slag cement	0.0224
Coarsest Portland cement	0.0255
Iron Portland cement	0.0204

Apparatus for Measuring Volume Change.—The British Standard Specifications for Cement recommends the Le Chatelier method. The paste is 1.18 in.

* *Zement*, December, 1921.

in diameter and 1.18 in. high, moulded inside a split metal tube. Arms attached to each side of the split multiply the movement of the tube due to volume changes of the cement paste.

The paste is submerged in water at 58 to 64° Fahr. for 24 hours, and the position of the arms indicated. The test piece is again submerged, the water brought to a boiling temperature in 25 to 30 min., and kept boiling for 6 hours. The mould is then removed from the water and allowed to cool. The indicator arms are then read, the difference between the two measurements representing the expansion.

The Bauschinger apparatus is an arrangement for measuring the change of length of a short bar, 100 mm. in length and 5 sq. cm. in cross-section.

M. Deval* has discussed the method of measuring variations in the volume of hydraulic cements. He refers to the tests of Durand-Klaye, Debray, Bauschinger, Kleve, and Le Chatelier, and concludes that the Le Chatelier method gives the most concordant results under which cement of good quality will not show more than 0.2% of swelling. He remarks that cements differ greatly in expansion and in rapidity of hydration.

(*2*) *Aggregate.*—Mr. Cloyd Chapman† reported the contraction of 1 : 2 mortar specimens at 16 weeks to be 0.197% using screenings as aggregate and 0.083 with sand. Concrete (1 : 2 : 4 mix) with screenings contracted 0.062%, and with sand 0.042 per cent. The specimens were 2 by 2 by 24 in. in size; the measurements began 24 hours after moulding.

No doubt the aggregate has an important influence. In many cases the cause of disintegration of exposed structures is to be charged to defective aggregates, especially those containing a large proportion of fine limestone dust or clayey material. Porous concrete with changing moisture content must be subject to strains due to alternate expansion and contraction.

(*3*) *Proportioning.*—Leanness of mix diminishes the volume change. A number of investigations evidence this. Thus, a comparison of neat cement with 1 : 3 mortar gives the results shown (percentage) in Table 12.

Evidently, as the mix becomes leaner the volume changes diminish.

Pearson's tests show the relative shrinkage of various mortars, the initial measurements being made while the specimens were plastic, as follows:

Mix.	Percentage of shrinkage.
Neat	0.217
1 : 1	0.123
1 : 2	0.110
1 : 3	0.109
1 : 4	0.094
1 : 5	0.086
1 : 6	0.084
Concrete 1 : 4	0.067
Concrete 1 : 6	0.050

* *Bulletin*, Société d'Encouragement pour l'Industrie Nationale, January 31, 1900, pp. 31–37.

† *Proceedings*, Am. Soc. for Testing Materials, 1924.

TABLE 12.—LEANNESS OF MIX AND VOLUME CHANGE IN PERCENTAGE.

Author.	Neat		Mortar 1:3.		Concrete.		Duration.	Size of specimen.	Age at initial measurement.	Reference.
	Exp.	Cont.	Exp.	Cont.	Exp.	Cont.				
Gary	0.026	0.129	0.018	0.053	....	....	28 D	.....	.....	Mitt. a.d. kgl. tech. Versuchsanstalt zu Berlin, 1899 Erganzungsheft.
Bauschinger	0.046	0.214	0.009	0.132	....	....	16 W	4.7" cubes	.....	J. Mitt. tech. Lab d tech. Hochschule in Munchen, Heft 8, 1879.
Schuman	0.082	....	0.021	.....	....	....	4 W	0.775 □"×3.9"	.....	Tonind. Zeit. 13-485, 1899.
Tornei	0.025	0.201	0.027	0.094	....	....	12 W	4.7" cubes	.....	Quoted by Gary A. S. C. E. 3 016, 1893.
Considere	0.079	0.132	0.028	0.050	....	....	9 W	.....	.....	Comptes Rendus 129-467, 1899.
Pearson	....	0.217	.....	0.109	....	0.050	9 W	1" × 4" × 24"	At time of moulding	A. C. I. Vol. 17, 1921.
Goldbeck	....	0.155	.....	0.078	....	0.054	6 M	8" □ × 5'0"	24 hours	Bulletin 532 U. S. Dept. Agric.
Chapman	....	....	....	.....	0.197	....	0.042	16 W	2" × 2" × 24"	" "	Proc. A. S. T. M. 1924.
Scofield	....	....	0.019	0.055	0.017	0.047	7 W	4" × 4" × 24"	" "	A. C. I. Vol. 13, 1917.
Matusomoto	....	....	0.0101	0.0503	0.005	0.036	60 D	2" × 3" × 24"	" "	Bulletin 126 Univ. of Illinois, 1921.
McMillan	....	....	....	.....	....	....	0 084	13 M	4" × 5" × 4'0"	" "	Eng. Record Apr. 17, 1915.
Swain	....	....	....	.....	....	....	....	12 W	5" cubes	" "	A.S.C.E. July 1887.
White	....	....	....	.....	....	....	....	6 M	1" × 1" × 4"	" "	Proc. A. S. T. M. 1911.

In the tests of Goldbeck on 8 by 8 in. by 5-ft. beams* a wet or dry mix of 1 : 2 : 4, or 1 : 3 : 6 concrete varied but little in contraction when exposed to air for 1 year, the extreme ranges in percentage as scaled from a diagram being as shown in Table 13.

TABLE 13.

	30 days.	60 days.	1 year.
1 : 3 : 6 mixed very wet (10 to 12% water)	0.023	0.033	0.053
1 : 3 : 6 mixed very dry (8.5% water)	0.034	0.045	0.055
1 : 2 : 4 mixed very wet	0.023	0.034	0.058
1 : 2 : 4 mixed very dry	0.035	0.040	0.055

Tests at Purdue University on gravel concrete when measurements began two days after moulding showed for 1 : 2 : 3.5 and 1 : 1.5 : 3 concrete an expansion in water during 40 days of 0.005%. During 150 days subsequent drying in air the contraction was 0.035 and 0.015%, respectively, the brands of cement varying in the two concretes.

Dr. Mörsch has recorded† tests of the influence of richness of mix and also of different varieties of sand and the volume changes due to swelling in water and shrinking in air. For one year the swelling in water continually increases

* *Bulletin No. 532*, U. S. Dept. of Agriculture, 1917.

† "Der Eisenbetonbau," Fifth Ed., Vol. I, pp. 32–33.

for neat cement, and for 1 : 3 and 1 : 5 mortars; the shrinkage in air reaches a maximum at 90 days. The relative values at the end of a year for swelling in water are:

Neat cement	180
1 : 5	45

For shrinking in air the values are:

Neat cement	150
1 : 5	52

The volume changes of mortar made with several sands seem to differ.

(4) *Size of Specimen and Forms.*—Evidently the size of the specimen, which affects the rapidity of loss and gain of moisture and the unequal distribution of moisture, will have a marked influence on shrinkage and expansion. Consequently, the data from many investigations are not comparable. Flat specimens will warp; there will be different frictional resistances due to the forms or to the bending on the supports. Moreover, the size of the specimen will control the early formation of surface cracks, which must affect the integral movements. Pearson has shown that absorptive forms will greatly reduce the shrinkage of mortar specimens. Graf has shown that shrinkage is lessened during early stages by forms with cast-iron ends. For these reasons the specimen itself and the technique of testing should be standardized for these tests which now seem to be of increasing importance. The specimens used range in nominal size from 5-in. cubes to prisms, 2 by 2 by 4 in., 2 by 2 by 24 in., 1 by 4 by 24 in., 1½ by 1 by 4 in., 4 by 4 by 24 in., 8 by 4 by 2 in., 8 by 8 by 40 in., and 8 by 8 in. by 9 ft.

Mörsch* shows the effect on tensile strength of varying the size of the test piece from 5 sq. cm. to 400 sq. cm. (Table 14).

TABLE 14.

Cross-section.	Tensile Strength, Neat.		Mortar.
	28 days moist.	7 days moist; 21 days dry.	
5 sq. cm.	33.4	44.8	1 : 1.34
100 sq. cm.	21.0	15.9	0.76
400 sq. cm.	17.6	12.0	0.68

The effect of desiccation of briquettes following 1 day in air and 21 days in water is shown by a rapid decrease in strength and a gradual increase in strength following a longer period of desiccation, until at 12 days the strength of the briquettes exceeded the strength at the time they were taken from the water.

One aspect of surface drying and the production of fine surface checks is the consequent loss of strength in cement briquettes which have been allowed

* "Der Eisenbetonbau," 1920, Vol. I, p. 121.

to dry subsequent to immersion and previous to testing. In 1904, Van Ornum* determined the effect on tensile strength of taking briquettes from the storage tank for various periods before testing. The strength of the neat Portland cement decreased as much as 50% when exposed to air from 1 day to 3 days.

M. Anstett,† Chief of Laboratories of the City of Paris, France, made similar tests in 1922, and reported the decrease in strength of neat briquettes tested at 7 days, 37 days, and 90 days, after having been removed from the water 7, 20, and 26 hours, respectively. If the briquettes are allowed to dry for 7 hours before testing a loss of strength of 10% may be expected. This becomes an important matter in standardizing cement testing. In the case of 1 : 3 mortar briquettes, the loss is less marked, approximately 5 per cent. The loss increases in proportion to the duration of the drying period.

No doubt the effect of drying will depend on the cement used, and the method of forming the briquette, on the rate of drying.

In a book by Foker and Barnes, on "Reinforced Concrete Design", published in 1912, they quote‡ tests on 1 : 3 mortar specimens that were cured in air 1 day and in water for 27 days, and afterward exposed to dry air for various periods up to 12 days. After a period of drying for 2 days the strength diminished 50%, following which it increased to approximately its value at the end of the water-curing period.

The surface shrinkage no doubt will affect the point in the extensibility of the tension side of beams at which hair cracks are observed. Beams carefully cured or saturated will probably show greater extensibility. A close analogy exists between concrete and wood that is case-hardened by defective kiln practice.

In the absence of reinforcement near the surface, it would appear that surface shrinkage might increase the number of hair cracks.

(*5*) *Exposure.*—Many early tests disclosed swelling in water and shrinkage in air. The wide ranges of values recorded were mystifying as the underlying controlling factors were not known. Exposures include immersion in water (cold or hot), a covering of wet burlap or damp sand, dry or moist air, all with various temperatures. The effects of humidity and temperature, while minor as compared to other factors, are not negligible.

The results of various measurements, therefore, are indicative of ranges rather than of definite application in specified cases.

Professor H. H. Scofield§ measured the change of length of mortars and concretes with and without an admixture of hydrated lime. The specimens were 4 by 4 by 24 in. He reports that the degree of volume change depends on the conjunction or opposition of temperature and moisture influences. A change of temperature in 1 : 5 mortar with fine sand screened out, age 8 weeks, from 33.8° to 180° Fahr., increased the length + 0.075%, or 0.00000535 per degree. In a change from 180° to 18° Fahr., the shrinkage was — 0.0664 per cent. From 22° in air to 107° Fahr. in water, the change was + 0.0377%; and from 107° Fahr. saturated to 18° Fahr. outside air, — 0.0467 per cent.

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* *Engineering News*, Vol. 51, p. 24.

† *Revue de Matériels de Construction et Travaux Publiques*, 1922, Vol. 148, p. 1.

‡ *Mitteilungen über Forsch.* und *deut. Ing.*, Heft 72–74.

§ *Proceedings*, Am. Concrete Inst., Vol. 13, 1917.

The changes of length due to absorption of water were found to be as follows: From 71.5° Fahr. in air, to 71.5° Fahr. in water (24 hours) + 0.0192%; from 71.5° Fahr. in air to 100° Fahr. in water (72 hours), + 0.040%; from 100° Fahr. saturated to 10.4° Fahr. in air, — 0.0553%.

For 1 : 5 gravel concrete giving a tensile strength of 2 314 lb. at the age of 7 weeks, these values become + 0.017%; + 0.036%; and — 0.0472 per cent.

In these tests a comparison is made between the shrinkage of wet and dry specimens under a sudden drop in temperature. The wet specimens shrank — 0.0553%, and the dry ones, — 0.0664 per cent. However, the sand used was different in the two cases.

Scofield's tests also show that admixtures of hydrated lime increase the volume and strength.

H. C. Berry,* M. Am. Soc. C. E., found that 1 : 2 : 4 concrete shrunk in air at 150 days, 0.023% and expanded in water, 0.020 per cent. This is less difference between shrinkage and expansion than in other experiments.

Mörsch† averages the results of tests on mortars, 1 cement and 3 sand, immersed in water for 7, 28, 90, and 196 days, and then allowed to dry in the air for periods ranging up to 4 years.‡ A set of test pieces was allowed to dry without immersion. His diagram is reproduced in English units in Fig. 21.

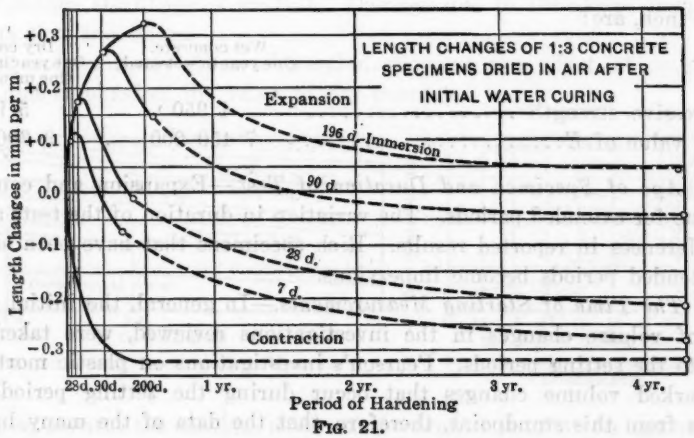

FIG. 21.

Professor F. R. McMillan,§ reviews tests of shrinkage specimens, 4 by 5 by 24 in., cured 2 weeks under wet burlap and afterward exposed to the ordinary air of the laboratory. The shrinkage was from — 0.055 to — 0.065 per cent. Initial readings taken when the beams were 1 day or 2 days old. The shrinkage amounts to — 0.05% within the first 6 days. The effects of varying the proportions, quantity of water, or density were small. He states that the minimum shrinkage to be expected in concrete that has been allowed to dry out thoroughly is — 0.05 per cent. Values from 20 to 50% greater will usually result; the difference in early curing conditions has little effect on the final shrinkage.

* *Proceedings*, Am. Soc. for Testing Materials, Vol. 11, 1911, p. 563.
† "Der Eisenbetonbau", Fifth Ed., Vol. I, Pt. I, p. 136.
‡ *Mitteilungen* des Materialienprüfungsamts, Lichterfelde, 1916.
§ *Transactions*, Am. Soc. C. E., Vol. LXXX (1916), p. 1378.

De Breuville* subjected reinforced plates to water pressure, off and on, to obtain the effect of moving water on the bond between mortar and steel. He concludes that moving water weakens the bond.

G. E. P. Smith, M. Am. Soc. C. E., explains† longitudinal cracks along the top of 20-in. concrete pipe at Tucson, Ariz., by the action of water swelling the bottom of the pipe. Experiments on dry pipe, partly submerged, appear to confirm this explanation. Tests of pipe, 28 days old, showed a strength of 2 624 lb. per lin. ft. for dry pipe and 1 790 lb. per lin. ft. for pipe that had been immersed for 5 hours.

Lagaard‡ tested 1:2:4 limestone concrete in compression. The specimens were cured for 7 days under wet sacks and approximately 450 days in air. One set showed a value of E of 3 700 000 and a compressive strength of 3 630. The other set subsequently immersed in water for 21 days showed a value of E of 3 150 000 and a compressive strength of 2 340, all in pounds per square inch.

Tests§ by G. M. Williams, Assoc. M. Am. Soc. C. E., showed no difference in the value of E, either for immersed or dry concrete, or for a low or high degree of consistency. In the discussion of this paper, Professor Walker, of the Lewis Institute, takes issue on this conclusion. His values, in pounds per square inch, are:

	Wet concrete. One year in wet sand.	Dry concrete. One year in wet sand. One month in air.
Compressive strength	4 950	5 920
Initial value of E	7 450 000	9 300 000

(6) *Age of Specimen and Duration of Test.*—Expansion and contraction continue for extended periods. The variation in duration of the tests accounts for differences in reported results. Rich specimens that have been saturated for extended periods become impervious.

(7) *The Time of Starting Measurements.*—In general, the initial observations of volume changes in the investigations reviewed, were taken subsequent to the setting periods. Pearson's investigations on plastic mortar show the marked volume changes that occur during the setting period. It is obvious from this standpoint, therefore, that the data of the many investigations are not to be compared.

In 1921,‖ Pearson investigated the development of change of length of mortars as time elapsed, especially during the first few hours. Up to 6 hours, while mortars were plastic, the shrinkage was moderate, but at the time of initial set, the volume changes were pronounced. They moderated after 10 hours. At the time of final set the material quiets down, and various cements then show about the same rate of shrinkage. When specimens were placed on non-absorptive bases the shrinkage at 64 days was: Neat cement, 0.21%; 1 : 3 mortar, 0.19%; 1 : 6 mortar, 0.084 per cent.

* *Annales des Ponts et Chaussées*, Sem. III, 1902.
† *Engineering News-Record*, 1919, v. 831.
‡ *Engineering News-Record*, November 14, 1918.
§ *Proceedings*, Am. Soc. for Testing Materials, 1920, p. 8233.
‖ *Proceedings*, Am. Concrete Inst., 1921, p. 135.

For the first two or three hours while mortars are still plastic, either moderate expansion or contraction may occur due to manipulation, forms, and the quality of the cement. At the time of initial set there is a tendency toward pronounced contraction which moderates at 8 to 10 hours when final set is approaching. From 12 to 24 hours is a period of comparative quiet, with slight shrinkage. There is then a long continued shrinkage which persists for many months; at one year this may range from 0.15 to 0.34 per cent. The volume change, therefore, is in two phases as follows: (1) Plastic, 12 hours, to, say, 24 hours; (2) rigid after 24 hours, changes here are independent of those in Phase (1).

Dr. Otto Graf,* of the Testing Laboratory of the Technical High School of Stuttgart, has made valuable investigations of the volume changes of mortars. The 1921 paper reports the progressive shrinkage of mortars from 1 hour to 28 days, and the effect of excess water. Four brands of Portland cement were used. The mortar was 1 : 1 by weight, and the water varied from 10% (firm consistency), 15% (soft consistency), and 19% (plastic consistency). The test piece was a disk, 15 mm. thick and 150 mm. in diameter, placed on oiled paper and moved under a microscope by a micrometer screw. His results are reproduced in Figs. 22 and 23. The importance of dry concrete and early curing to reduce shrinkage is evident. Damage due to shrinkage originates during the first ten hours.

Fig. 23 substantiates Abrams' results, showing the effect of water on strength, and emphasizes the value of dry concrete.

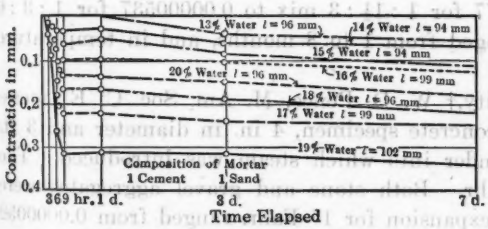

FIG. 22.—SHRINKAGE OF 1 : 1 MORTAR.

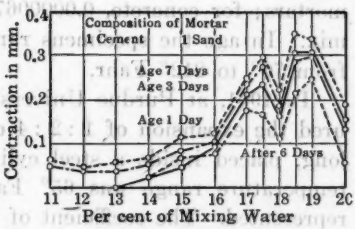

FIG. 23.—EFFECT OF WATER ON SHRINKAGE.

Graf also reports the marked effect of the cement content on the volume change. The shrinkage in a length of 100 mm. was as shown in Table 15.

TABLE 15.

Time.	9 hours.	7 days.	1 day to 28 days.
Neat cement	0.42 mm.	0.52 mm.	0.13 mm.
1:1	0.32 "	0.38	0.08 "
1:4	0.05 "	0.13	0.07 "

The four brands of cement used varied greatly as to the volume changes during the first 9 hours.

* *Beton und Eisen*, 1921–22.

In tests of prisms, 80 mm. square and 400 mm. long made to detect the differential movements between the concrete and the embedded reinforcing bars, it was found that within the first day while considerable changes in volume took place in the mortar, no changes of length were recorded in the reinforcement. This condition lasted for three days.

In the 1921 tests of Graf, wax and oil were used to prevent the mortar from adhering to the sides of the moulds. In 1922, moulds of cast iron were used to study the effect of adherence of the concrete to these surfaces. Reinforced specimens were also studied. The concrete was 1 : 1.2 : 1.8, using 11.8% water.

It was shown that the contact with the ends of the cast-iron moulds lessened the natural shrinkage of the concrete. Reinforcement considerably reduced the shrinkage of concrete during the first day after moulding; plain concrete specimens show a reduction, in a length of 333 mm., of 0.004 cm. and reinforced concrete, of 0.0008 cm., after 9 hours. After 14 days, these values become 0.0024 and 0.0004 cm., respectively.

Volume Changes Due to Temperature.—The generally accepted value of the coefficient of expansion for concrete due to temperature is 0.0000065 for 1° Fahr. It is assumed to be constant throughout the ordinary ranges of temperature.

Professor Mills, of Cornell University, reports* a series of tests for the coefficient of temperature expansion using test pieces 8 by 4 by 2 in. The coefficient ranges from 0.00000783 for neat cement to 0.00000577 for 1 : 5 mortars; for concrete, 0.00000677 for 1 : 1½ : 3 mix to 0.00000537 for 1 : 3 : 6 mix. In age the specimens ranged from 1 to 8 months, and in temperature from 70° to 212° Fahr.

In 1901, at Purdue University,† W. D. Pence, M. Am. Soc. C. E., measured the expansion of 1 : 2 : 4 concrete specimen, 4 in. in diameter and 3 ft. long, placed inside a steel cylinder into which steam was introduced. The temperature range was 65° Fahr. Both stone and gravel aggregates were represented. The coefficient of expansion for 1° Fahr. ranged from 0.0000052 to 0.0000057 in stone concrete; a stone bar showed 0.0000056; gravel concrete averaged 0.0000056. These tests well represent average values. However, it was assumed that the coefficient is equal throughout the range of temperature, and no doubt there was also expansion due to the steam, if it was moist.

Fig. 6 shows results of tests at Purdue University. The observations were conducted on completely dried specimens only, so that there is no error due to the change in length with fluctuations in the moisture content of the concrete.

Plastic Flow.—The yielding of concrete under continued loads was noticed at an early date, especially in laboratory tests to determine the modulus of elasticity. This plastic flow became of practical importance in specifying and measuring deflections of loaded floor panels. Later, it became apparent that it produced a readjustment of stresses between steel and concrete which was important from the standpoint of the design of floors and columns.

* "Concrete Engineer's Handbook", Hool and Johnson.

† *Journal*, Western Soc. of Engrs., 1901, Vol. 6, p. 547.

Several investigations have been made to determine the plastic flow or the time effect, a bibliography of which follows:

Hatt, W. K., *Proceedings* Am. Soc. for Testing Materials, 1907, p. 421.
Studies in Engineering No. 3, Univ. of Minnesota, 1915.
Janni, A., *Transactions* Am. Soc. C. E., Vol. LXXX (1916).
Fuller, A. H., and C. C. Moore, *Proceedings* Am. Concrete Inst., 1916.
Smith, E. B., *Proceedings* Am. Concrete Inst., 1916.
Goldbeck, A. T., and E. B. Smith, *Proceedings* Am. Concrete Inst., 1916.
McMillan, F. R., *Proceedings* Am. Concrete Inst., Vol. XVII, 1917.
Smith, E. B., *Proceedings* Am. Concrete Inst., 1917.
Hollister, S. C., *Proceedings* Am. Concrete Inst., 1919, p. 137.
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McMillan, F. R., *Proceedings* Am. Concrete Inst., 1921.

THE ATMOSPHERE AND ITS RELATIONS TO HUMAN HEALTH AND COMFORT*

C.-E. A. WINSLOW,† ESQ.

When the wise king of the Hebrews sought to express the fundamental unity of the problems which confront each human life he began with the atmosphere. "When I was born", he says, "I drew in the common air, and fell upon the earth, which is of like nature, and the first voice which I uttered was crying, as all others do." "The common air" is indeed the basic condition of human existence, controlling it in more ways than are yet fully realized. The atmosphere in its relations to human health and comfort seems, therefore, a topic peculiarly appropriate for consideration by a group of men whose objective is the application of the principles of engineering science in the special field of sanitation.

The chief business of science, as the speaker understands it, is to unify and simplify conceptions of the chaos of phenomena by relating those phenomena to underlying laws and principles. This task is more difficult in biology than in mechanics or hydraulics because the reactions of living matter are more complex than those of non-living substances. The basic conditions of life are, however, suspectible of relatively simple statement. From the amœba to man, from the bacterium to the oak tree, the life process depends upon at least five essential factors, each present to an extent above a certain minimum and in general below a certain maximum. The five positive essentials are:

1.—Food (including under this term regulative mineral salts).
2.—Oxygen.
3.—Water.
4.—Temperature.
5.—Light.

In addition to these positive essentials, there must be freedom from:

1.—Mechanical injury.
2.—Toxic chemical substances.
3.—The attacks of hostile living beings, predatory or parasitic.

The list is obviously not a logically complete and perfect one. One factor, that of atmospheric pressure, which is omitted from the list will be discussed. The speaker is inclined, however, to believe that it includes all but a minor fraction of those influences which under actual conditions affect the vital

* Presented before the Sanitary Engineering Division, New York, N. Y., January 20, 1925.

† Prof. of Public Health, Yale School of Medicine, New Haven, Conn.

processes of animals and plants. Taking it for what it may be worth, it will be noted that so far as man is concerned in all but one of the life factors noted, the atmosphere plays a more or less important rôle. We do not derive food directly from the air about us, although our supply of plant food depends largely upon atmospheric nitrogen, and the prevalence of goiter in certain regions is correlated with the presence or absence of iodine salts blown inland from the sea. Oxygen, temperature, and light as they affect the human body and to a less extent the aqueous exchanges of the body, are directly related to atmospheric conditions; whereas the air may bear with it physically injurious dust particles, toxic gases, and, under certain conditions, the microbes of disease.

Composition and Characteristics of the Atmosphere

Before proceeding to discuss the more significant deviations from normal atmospheric conditions, as they affect health and comfort, it will be desirable to recall for a moment what these normal conditions are, to which the human body is presumably more or less perfectly adapted.

The atmosphere of the earth is a layer of gases, of continuously decreasing density as one passes outward from the surface of the earth itself, and of varying composition, when one reaches a distance where the decrease of gravitational force is so great as to show a marked differential effect upon its various constituents. Thus, at a height of 20 km., it is estimated by Wegener that argon has practically disappeared and oxygen reduced to 15%, whereas nitrogen has increased to 88 per cent. At 100 km., oxygen and nitrogen have practically disappeared, the atmosphere consisting of 67% hydrogen, 4% helium, and 29% of a hypothetical gas lighter than hydrogen, which Wegener called geocoronium. Whether or not these assumptions are sound is, however, of little practical moment to the sanitarian. The atmosphere as a whole has been estimated to be made up of nearly 4 000 000 000 tons of nitrogen (73% by weight), more than 1 000 000 000 tons of oxygen (23% by weight), nearly 160 000 tons of argon and other inert gases (3% by weight), and more than 50 000 tons of water vapor (1% by weight). As water vapor is so highly variable a constituent it is usually omitted from statements of the normal composition of the atmosphere; and this normal composition at or near the surface of the earth may be stated in the usual form as nitrogen, 78.1% by volume, oxygen, 20.9% by volume, and argon, 0.9% by volume. Carbon dioxide is normally present to the amount of 0.03% and the inert gases other than argon (neon, helium, krypton, xenon) in still smaller proportions.

The constancy of the relation maintained between the four principal gaseous constituents of the atmosphere is a striking phenomenon. Nitrogen and argon, being relatively inert, might be expected to show but slight variation. Oxygen on the other hand is constantly being removed by the respiratory action of plants and animals and by processes of combustion and is constantly being contributed by the process of photo-synthesis as carried out in the green parts of plants during the day. Carbon dioxide is being consumed in the process of photo-synthesis and in the secretion of calcareous skeletons by various animals; while it is produced by respiration, by combustion, and by volcanic

action and other subterranean processes. The extent of these changes may be suggested by the calculation that 1 hectare of oat field or forest (about 2½ acres) consumes in an average summer season about 11 000 kg. of carbon dioxide and gives off about 8 000 kg. of oxygen. These changes produced by 1 hectare of agricultural land during the summer would be just about balanced by the respiratory activity of 32 human beings, during the whole year.

With carbon dioxide, the waters of the ocean exert an important regulative influence, dissolving in the form of bi-carbonates any excess of the gas and yielding it up again as carbonic acid when the partial pressure in the air above decreases. As a net result of these complex processes the proportion of oxygen in winter or summer, in town or country, and even in the interior of dwellings, rarely varies near the surface of the earth beyond the extreme limits of 20 and 21% of the atmosphere by volume; the variations in carbon dioxide as will be pointed out subsequently are somewhat wider.

Atmospheric moisture on the other hand varies widely from exceedingly small proportions to a point of approximate saturation. The saturation point itself depends directly upon the temperature of the atmosphere. Air at 0° Fahr. will hold only 0.5 grains of water vapor per cu. ft.; at 20° Fahr. the amount increases to 1.2 grains; at 32° Fahr. to 2.1 grains; at 68° Fahr. to 7.5 grains; and at 98° Fahr. to 18.7 grains. Thus, there is actually more moisture per cubic foot in air at 80° Fahr. with 20% relative humidity than in air at 35° Fahr. with 80% relative humidity; but the warmer air of lower relative humidity will be much more avid in absorbing moisture from the body or other moist surfaces and will thus be much more drying in its physiological effects. Desert air and the air of heated rooms in cold climates may fall as low as 10% of their potential saturation value.

In addition to its various gaseous constitutents the atmosphere usually contains a greater or less proportion of minute suspended particles in the form of dust, the significance of which will be discussed in a subsequent paragraph; and, finally, in even the briefest review of the composition of the atmosphere, we must mention living micro-organisms, present only in very small numbers in pure outdoor air, as Pasteur demonstrated when he opened his flasks of putrescible liquid upon the Mer de Glace, but often rising to hundreds per cubic foot indoors and, when considerable contaminated dust is present, even to much higher figures.

The Physiological Effects of Atmospheric Pressure

The first problem which naturally suggests itself in connection with the relation of the atmosphere to human health and comfort is that of the influence of quantitative changes in concentration due to differences in atmospheric pressure. The pressure itself is apparently not a factor of primary importance although under certain circumstances sudden changes in pressure may produce serious and even fatal results. In the construction of tunnels and the laying of foundations the workers in caissons are exposed to pressures which may exceed three or four atmospheres. While under an excess pressure of even 50 lb. per sq. in. no marked discomfort is experienced, if this return to normal pressure is made too rapidly, caisson disease or compressed air illness fre-

quently results. In the building of the tunnels under the East River, New York, N. Y., 3 692 attacks of compressed air illness with 20 deaths were recorded in a group of 10 000 employees. The pathology of this disease appears to be a relatively simple one, originating in the direct liberation within the blood vessels or tissues of bubbles of nitrogen gas with inevitable mechanical injury; and of course the condition can be controlled by regulated and gradual decompression.

Far more important than such direct variations in atmospheric pressure are the indirect effects due to changes in oxygen concentration. Oxygen is after all the most essential contribution of the atmosphere to human health and comfort; and the predecessors of Galen when they taught that the arteries were ducts for the transportation of air were after all very close to a physiological truth. As one passes upward from sea level the reduction in atmospheric pressure soon produces a reduction in partial pressure of oxygen which has real physiological significance. Thus, at 5 000 ft. above sea level the partial pressure of oxygen corresponds to 17.5% of the atmosphere at sea level (instead of the normal 21 per cent). Even at this point a few individuals begin to show an accelerated heart beat. At 10 000 ft. the concentration of oxygen is only 14.2% of a sea-level atmosphere and symptoms are more marked and more general. Beyond 13 000 ft., with concentrations below 12.7%, mountain sickness becomes a serious problem—a problem created entirely by deficiency in oxygen. The gallant struggle to conquer Mt. Everest, which has been followed with such eager interest during the past few years, is first and foremost a struggle against oxygen starvation and cannot be successful unless means are found for transporting oxygen apparatus for the use of the climbers who are to accomplish the last few hundred feet of rock which still tower unconquered into the sky. For the aviator too this problem is of the most pressing import. Bombing and observation planes are able to fly for hours at heights of 12 000 ft. or more and pursuit or battle planes not infrequently reach altitudes of 20 000 ft. The so-called "air staleness" among pilots is merely mountain sickness in a pronounced form, and the studies made by the Medical Research Laboratory of the Air Service at Mineola, N. Y., along lines outlined by the speaker's colleague, Yandell Henderson, have shown how the worst effects of this malady may be avoided by the selection of pilots shown by specially devised tests to be peculiarly resistant to low oxygen pressure.

Chemical Problems of Ventilation

On mountain tops and in the vast spaces of the empyrean where the airman goes, the most serious atmospheric hazard is the lack of oxygen. At the other extreme of human pioneering—in the bowels of the earth—the same danger is met in a different form. In the deep parts of mines, and in old wells, the normal atmosphere may be replaced to so great an extent by carbon dioxide that men entering such places may perish of oxygen starvation. On the surface of the earth itself, however, in the normal haunts of man, the problem of oxygen content need give no concern. Even in the worst ventilated classroom or auditorium or workshop the oxygen in the atmosphere never falls below 20%, on account of leakage through cracks and the rapid diffusion

which takes place even through solid walls and ceilings. Lavoisier, as early as 1777, showed by animal experiments that the symptoms experienced in a badly ventilated room could not be attributed to oxygen deficiency. It is only when the partial pressure of oxygen falls from its normal 21% of an atmosphere to a value of 16% or less that important physiological reactions are involved.

Lavoisier himself believed that the evil effects of vitiated air were due to the toxic effects of carbon dioxide, and this view was held by physiologists for about a hundred years. It was Pettenkofer in 1863 who first clearly enunciated a third theory, that the influence of bad air was due to the presence of toxic organic substances excreted into the atmosphere from the human body. In his criticisms of the carbon dioxide theory, at least, Pettenkofer has been supported by all subsequent observers. The presence of carbon dioxide is indeed of fundamental importance in relation to human life, as it is the concentration of this gas in the blood which determines the activity of the respiratory mechanism. In the absence of carbon dioxide, breathing would cease and asphyxia result and the increased depth and rate of respiration after vigorous physical exercise is the direct result of increased carbon dioxide in the blood stream. An atmospheric concentration of 2% of this gas causes an automatic increase of about 50% in depth of breathing just such as occurs with moderate exercise; and in breweries and mines such concentrations are actually borne with no appreciable discomfort. In the worst ventilated rooms carbon-dioxide content rises only from the normal 0.03% to about 0.5% of an atmosphere and such a change as this is well below the threshold of physiological significance.

On the other hand, Pettenkofer's alternative hypothesis of toxic organic substances in respired air has proved as untenable as the carbon-dioxide theory in explanation of the physiological phenomena characteristic of badly ventilated rooms. Revived again and again, by Brown-Sèquard, Weichardt, and other physiologists, the assumption of such organic poisons has repeatedly been disproved by more careful studies. Certain subtle psychological responses to the presence of atmospheric odors will be considered subsequently, but it is clear that the ordinary sensations experienced and the ordinary physiological responses manifested in a badly ventilated room are due neither to reduced oxygen nor to increased carbon dioxide nor to the presence of hypothetical organic poisons. Human occupancy of a confined space produces five different changes in the atmosphere, namely, decrease of oxygen, increase of carbon dioxide, increase of products of organic decomposition (as evidenced by the "body odor"), increase of temperature, and increase of moisture. The first three having been shown to be inadequate to explain the effects of bad air, we must turn to the last two. As Professor Lee has summarized the situation in epigrammatic form, "the problem of ventilation is physical, not chemical, cutaneous not respiratory."

Thermal Problems of Ventilation

It was Hermans, of Amsterdam, Holland, who, in 1883, first clearly enunciated the theory that the evil effects of bad ventilation were primarily due to overheating and consequent interference with the elimination of heat

from the surfaces of the body. This view was confirmed in 1905 and succeeding years by Flügge and his associates at Breslau, Germany, and, later, by Hill and Haldane in England and by Benedict and the New York State Commission on Ventilation in the United States. In one form or another these investigators have repeated a single crucial experiment which may be schematically described as follows. A group of subjects is placed in a closed experimental chamber and kept there while oxygen decreases and carbon dioxide, organic matter, temperature, and humidity increase. They manifest the usual symptoms characteristic of "vitiated" air—headache, general discomfort, lassitude, changes in blood pressure, pulse rate, and the like. The attempt is then made to relieve these symptoms in two alternative ways—by permitting the subjects to breathe chemically pure air (admitted, for example, through a tube from outside), or by lowering the effective temperature of the chamber by cooling coils or the operation of fans, without altering its chemical composition. The first procedure is ineffective, the second completely effective.

It will be noted that the vitally important point in all this is the rate of heat loss from the skin and that this rate of heat loss will depend on the combined influence of three distinct atmospheric factors, temperature, humidity, and air movement. When the temperature is low, heat loss from the body surface is effected chiefly by direct conduction and convection and as moist clothing conducts more readily than dry clothing, moist cool air feels colder than dry cool air. At high temperatures on the other hand, the body loses heat chiefly by evaporation and as atmospheric moisture hinders this process, moist warm air feels hotter than dry warm air. At temperatures below that of the body, air movement accelerates heat loss and plays such an important rôle that still indoor air at 72° Fahr. may be really "warmer" from a physiological standpoint than a breezy outdoor atmosphere at 90° Fahr.

Recent investigations, particularly those carried on in New York, have made it clear that these thermal problems of ventilation are of the very first importance, and that even slight degrees of overheating may produce far-reaching results. In the first place the studies of the New York State Commission showed that even an atmospheric temperature of 75° Fahr. in still air caused a definite increase in body temperature and heart rate, a marked decrease in general vasomotor tone, and an increased rate of respiration. In the second place this relatively slight overheating caused a decrease of 15% in the physical work performed by subjects not compelled to maximum effort but stimulated by a moderate cash bonus. The inferences from this fact in regard to the economic losses due to overheated factory workrooms are of far-reaching significance. Finally, the studies showed that in fan-ventilated schoolrooms, at an average temperature of 68.5° Fahr., there was an excess in respiratory illness amounting to 70% and an excess in absence due to such illnesses of 18%, as compared with window-ventilated schoolrooms at an average temperature of 66.5° Fahr.

The conclusions to be drawn from these investigations are of immediate practical importance to ventilating engineers, architects, schoolmen, and legislators. In a large number of States there are now laws which require the

positive ventilation of schoolrooms by methods which effect an air change at the rate of 30 cu. ft. per min. These laws have been advocated by the American Society of Heating and Ventilating Engineers in complete good faith on the basis of the older physiological assumption that air vitiation was a chemical condition requiring a definite degree of dilution for its control. The New York State Commission results make it clear that the supply of 30 cu. ft. per min. of air in the schoolroom is not only needless but actually harmful to health and comfort as it almost inevitably leads to objectionable overheating. In the interest of health and of economy these laws should be modified so as to permit of the construction of school buildings ventilated by regulated window inlets and gravity exhaust which the New York studies have shown to be, under some conditions at least, distinctly preferable to the fan-pressure system.

Climate and Season and Disease

The new conceptions of ventilation here outlined make it clear that detrimental air conditions may exist outdoors as well as in and that in midsummer the whole world may be considered as badly ventilated. The prevalence of summer diarrhea of infants has been shown to bear a direct causal relation to summer temperature, and it would be well for architects and engineers to realize that August heat is as harmful as February cold and that provisions for specially cooled rooms and buildings in summer are as logical as those which we now make for heated buildings in winter. The speaker's colleague, Professor Ellsworth Huntington, has shown by exhaustive and carefully controlled statistical studies that the efficiency of factory labor reaches a maximum when the mean temperature for the 24 hours averages about 60° and that the death rate (based on figures for about 9 000 000 deaths) is at a minimum when the mean temperature for the 24 hours is 64° Fahr. and the mean relative humidity is 80 per cent. Professor Huntington points out that a climate which is essentially ideal from the standpoint of moderate temperature and humidity and stimulating variability exists only in Western Europe, in the Northeastern and North-Central United States, in Japan, and in parts of Australasia, and we may be prepared to agree with him that a favorable climate has been one of the major factors in the development of the dominant civilizations of the world.

The Physiological Effects of Sunlight

The relations between the atmosphere and the human body with respect to oxygen, temperature, and moisture have been reviewed briefly. Of the four primary physiological relationships of the aerial envelope there remains only that of sunlight to be considered.

The value of sunlight as an adjunct to health has been stressed by hygienists since the days of the Greeks. In the medieval code of the School of Salernum prominent place is given to the admonition,

"Let air you breathe be sunny, clear and light,
Free from disease, or cesspool's fetid blight."

Soft coal was introduced into London about the end of the Thirteenth Century and almost at once an agitation against the "smoke nuisance" began, leading even in the reign of Edward I to a prohibition of the use of soft coal during the sessions of Parliament. English authorities have devoted much attention to this problem during the past few years and have demonstrated the astounding fact that between 80 and 400 tons of solid matter per annum is deposited from the air of English cities on every square mile of territory. In Manchester and Leeds, England, and Glasgow, Scotland, it has been shown that the average amount of winter sunlight is diminished about 40% as compared with adjacent rural districts and Besson reports that the smoke of Paris causes a reduction in sunlight of 15 to 25% as far as 10 km. from the city.

In this country, the Cleveland, Ohio, Chamber of Commerce has estimated the financial loss due to smoke at $12 per capita per annum.

So far as the effects upon health are concerned, it must be remembered that the whole theory of the beneficial effects of sunlight has rested in the past on a purely empirical basis. Various authors reported statistical studies indicating that the death rate was higher in smoky cities than in rural districts and in the smoky winter season than in summer; but conclusions drawn from such analyses as to the harmful effect of a smoky atmosphere *per se* were clearly fallacious. Too many of what the late George C. Whipple, M. Am. Soc. C. E., has called "concealed classifications" were involved for any sound distinction between the influence of smoke and the influences of urban life or of the winter season as a whole. Even the revival of the cult of Apollo by Rollier and his Swiss colleagues in the treatment of tuberculosis by exposure to sunlight rested on purely clinical observations which were not altogether convincing, in view of the fact that tuberculous patients who live a hygienic life so generally recover whatever other special treatment they receive. Of sound and incontrovertible experimental evidence as to the hygienic and therapeutic value of sunlight there really was none until five years ago. The conscientious teacher of hygiene, when he came to such problems as that of the smoke nuisance, was forced to buttress his case by ingenious hypotheses as to the effect of soot in causing people to keep their windows closed, or in leading them to form habits of personal uncleanness; but he was never quite happy about the matter.

When Huldschinsky in 1919 showed that irradiation with sunlight or with the quartz mercury vapor lamp prevented and cured rickets, a new chapter in physiological science was opened. The work of Hess in New York, and of Park at Baltimore, Md., and New Haven, Conn., has made it clear that rickets can be controlled by two apparently distinct agents, the administration of cod liver oil and irradiation, neither obviously related to the abnormalities of calcium and phosphorus metabolism which characterize the disease in itself.

Now come Steenbock and Black and Hess with the demonstration that foods which do not in themselves possess anti-rachitic value may be endowed with such a value by exposure to ultra-violet light; and finally Kugelmass and McQuarrie with the really epoch-making discovery that a long series of substances curative of rickets actually possess the power, when oxidized, of black-

ening the photographic plate as ultra-violet rays would do, while substances which do not cure rickets fail to produce this effect. Furthermore, they find that anti-rachitic substances when irradiated give off oxygen, so that the apparently independent action of sunlight and cod liver oil turns out as Park predicted to be truly an interdependent one. When cod liver oil is given to cure rickets we are really administering "bottled sunlight". The possibilities for general physiological theory (in regard to such oxidative processes as those associated with hemoglobin and chlorophyll, for example) which are opened up by this discovery of the relation between oxidation and radiation are no less than astounding; and as light rays influence general body metabolism so profoundly in the case of rickets, it is altogether reasonable to suppose that they may do so in tuberculosis and other conditions.

For the practical hygienist the chief immediate point is that there is now a rational justification for the instinctive belief in the value of sunlight, a new ground for controlling the smoke nuisance, demanding sound building laws, and advocating the outdoor life. The superiority of scientific knowledge over empiricism is well illustrated, however, by the fact that sunlight admitted through glass is robbed of its most valuable radiations and, as Bovie has shown in his studies of diseases of fowls at the University of Maine, at Orono, this problem may perhaps be solved by the use of windows made of fused quartz. Our fathers were right in believing that sunlight was a good thing; how it really acts and how its benefits can most practically be secured we are just beginning to comprehend.

Bacteria in the Air

In addition to the normal and universal constituents of the atmosphere there are certain suspended materials generally present in greater or less amount, and among such suspended particles are living microbes of various sorts, to which much sanitary importance was attributed in the past. When Lister devised his first antiseptic spray in 1867, it was the microbes in the air which loomed largest in his mind as potential factors in wound infection, and the work of Tyndall and others demonstrated that as far as the decomposition of organic liquids was concerned the germs carried by air might indeed play a predominant rôle.

Since those microbes which are present in air, are largely carried on minute dust particles, it is of interest to note that the bacterial content of dust is a considerable one. Kligler and the speaker have found an average of about 50 000 000 bacteria per gramme in the dust of city streets and between 3 000 000 and 5 000 000 in indoor dusts. Most of these bacteria are of course of harmless saprophytes types, but about 1 in 1 000 of the street dust microbes and 1 in 4 000 of the indoor microbes were of an intestinal type, whereas 1 in 1 000 of the street organisms and 1 in 200 of the indoor organisms were members of the group of *Streptococci* characteristic of the human mouth. From 5 to 20 tubercle bacilli per gramme have been found in the dust from places occupied by tuberculous patients.

Of the dust which may be collected from floors and other surfaces, the amount which actually gets into the atmosphere is after all very small, except

when the dust is stirred up by dry sweeping or violent winds. The actual bacterial content of the air is therefore generally low. In one of Pasteur's classic experiments, he opened sterile flasks of putrescible liquids (previously heated and sealed so as to contain a vacuum which would cause an inflow of air when they were opened), in various localities. Of twenty flasks thus exposed to normal country air at Arbois, eight showed the presence of micro-organisms; while of similar series opened on the slopes of the Lower Jura Mountains only five spoiled; and of a third series exposed on the Mer de Glace one only became infected.

Browne and the speaker have found in country air an average of 56 microbes per cu. ft.; in city streets an average of 72; in the indoor air of offices and schools about 95; and in factories, 113. Streptococci characteristic of specific mouth pollution were present to the number of 11 to 12 per 100 cu. ft. in outdoor air, 22 per 100 cu. ft. in offices, 30 in schools, and 43 in factories.

Such a bacterial content as this appears to have no important practical significance and as far as the transmission of disease microbes through the general medium of the atmosphere is concerned, epidemiological evidence is overwhelmingly negative. It has been made clear that even the widely distributed pus organisms get into wounds not from the air, but from the skin of the patients or the instrument which produced the wound or other objects which have come in contact with it; while the experience of well managed hospitals has shown that it is possible to care for various communicable diseases in a single open ward without serious danger of cross-infection, if aseptic technique is rigorously maintained.

Within a range of a few feet the direct discharge of mouth spray from an infected person is of course a real and important danger. Trillat, in Paris, has shown that bacteria suspended in moist droplets penetrate a cotton filter far more readily than when aspirated in a dry powder and that bacteria when inhaled by animals in droplets are drawn into the deepest parts of the lungs very quickly, while when borne by dry dust they are almost completely caught and held by the moist mucous membranes of the upper nose and throat, a phenomenon which the speaker suspects may be related to the electrical charges borne by the respective types of particles. The whole problem of droplet infection is, however, more nearly related to contact than to general atmospheric pollution. The mouth spray is a fine rain which settles quickly to the ground, not a vapor which disseminates itself through the air, and Robinson and the speaker have found that the vast majority of the bacteria discharged in coughing, sneezing, and loud speaking, disappear from the air beyond a radius of a few feet.

Problems of Atmospheric Dust

The microbes of the atmosphere of course constitute only a minute fraction of the suspended matter which it normally carries. Lifeless organic particles and finely divided inorganic matter are present almost everywhere and are made manifest by the reflection of light as the dancing motes in a sunbeam. Such particles play an important part in promoting the formation of fog and rain, serving as nuclei for the condensation of atmospheric

moisture; and to the reduction in the amount of aerial dust is due the clearness of the air after a heavy rain. As Tyndall showed in his classic experiments the larger of these particles will disappear so completely from the air in a closed box with glycerine-covered walls that a beam of light passed through the box is entirely invisible. Part of this dust is raised from dry surfaces by the wind like that borne into the City of Pekin from the Gobi Desert. Part comes from volcanic eruptions. The dust discharged during the great eruption of Krakatoa remained for several years in the atmosphere and traveled many times around the globe. Another important fraction of aerial dust is of extra-terrestrial origin because in addition to the 20 000 000 meteorites a day which appear as "shooting stars", finer "mineral particles of foreign source are constantly pouring through our atmosphere in the form of a dry and invisible rain."

The number of dust particles which may be detected in the examination of air depends very largely upon the method of sampling and analysis. Optical methods which depend on the depth of fog produced by condensation of moisture on the dust particles in a vacuum tube may show billions of particles per cubic foot in ordinarily clear air. For practical purposes it seems probable that the more minute of the motes in the sunbeam are of little practical importance and most methods of examination depend on the collection of dust particles by water-spray or by impingement in water or on a vaselined plate and on the counting of the particles under the microscope, a procedure which gives in the main those particles with a diameter between 1 and 10 microns. Counts made with the Palmer water-spray apparatus show less than 10 000 particles per cubic foot, (and less than 0.001 mg. per cu. ft.) in country air after a rain and 23 000 particles outside the fifty-eighth floor of the Woolworth Building; as compared with 118 000 particles per cubic foot in the street outside the Woolworth Building and about the same number (100 000) in ordinary indoor air. In dusty factories, on the other hand, the number of dust particles may rise to millions. In an abrasive factory at Niagara Falls the average of nine air samples gave the astounding result of 159 779 000 particles (7.805 mg.) of dust per cubic foot of air.

The influence of atmospheric dust upon health varies even more with the kind than with the gross amount of dust which may be present. As to the effect of organic dusts little exact and conclusive information is available. Coal dust and cement dust when inhaled in considerable quantities appear quite definitely to favor acute respiratory infections, such as bronchitis and pneumonia, but if anything tend to diminish liability to tuberculosis. Silica dust, on the other hand, has a peculiar and characteristic influence in predisposing the tissues to the invasion of the tubercle bacillus. How far this may be due to the fact that silica particles are less readily eliminated from the lung tissues than carbon particles and, therefore, produce more far-reaching fibrotic changes through their irritating action; how far to some specific influence of silica in attracting or fixing tubercle bacilli in its vicinity; and how far to other factors as yet unrecognized, cannot be stated. The end result, however, is beyond dispute, as is clearly shown by the vital statistics of sand-blasters, granite cutters, polishers, and grinders, and other workers

exposed to siliceous dusts. The City of Barre, Vt., in the center of the granite-cutting district, showed for a 10-year period a tuberculosis death rate more than 250% of that of the State of Vermont as a whole. In a certain axe factory in Connecticut, the men employed in grinding and polishing suffered from a tuberculosis mortality more than 1 180% that of their follow employees in the same factory not exposed to silica dust. Seventeen men out of every thousand in this group of grinders and polishers died every year as a direct result of industrial tuberculosis.

It is evident from these facts that the presence of fine particles of silica dust is one of the most deadly characteristics which the atmosphere can possess; and that definite measures for the protection of the worker in dusty trades, by the use of enclosed or moist processes, by the installation of local exhaust ventilation, or by the provision of masks and respirators, is of primary and essential importance.

Industrial Poisons

In addition to these siliceous dusts which so strikingly predispose to tuberculosis, the industrial hygienist must also contend, in certain crafts, with atmospheric dusts and with fumes and gases of a specifically toxic nature. In the State of Ohio, to take only one recently reported body of statistics, there were reported to the State Department of Health during a period of 10 years, 1 295 cases of industrial lead poisoning, and the vast majority of such poisonings are due to the inhalation of lead dust and fumes. In the hospitals of Detroit, Mich., during three years, there were treated 108 cases of lead poisoning, of which 67 occurred in a single factory among a group of men employed in the dry sand-papering of lead paint. The remedy here, as in many other processes, lies in the adoption of methods which will prevent the dissemination of atmospheric dusts of poisonous nature, but where this cannot be accomplished, the protection of the workers by masks and respirators should be enforced.

Lead is still the most important of the purely industrial poisons, but there are many others which affect smaller groups of workers in a more or less intensive degree. Mercury salts which cause the "hatter's shakes", arsenic, and other heavy metals, the oxides of nitrogen which produce acute and often fatal injuries to the lungs of munition and chemical workers, the irritant halogens, and a whole host of organic poisons, such as anilin and benzine and their derivates, are all common and serious industrial poisons. The increasing use of benzol in industry has attracted special attention during the past few years; a Committee of the National Safety Council has been studying the problem, with the conclusion that the danger from this substance is a real one but that it can be largely controlled by efficient local ventilation.

Of more than purely industrial significance is the menace of carbon monoxide poisoning. Unlike carbon dioxide, this gas is an active poison attacking the red cells of the blood; and it is discharged into the atmosphere under a wide variety of conditions which involve the one common factor of imperfect combustion. In industry, employees about blast furnaces, electric ovens, and similar installations are stricken down in almost instantaneous

death when exposed through some accident to a heavy dose of this gas. In the home, fatal cases of carbon monoxide poisoning are increasingly common, due to defective heating fixtures or to the use in small rooms of gas heaters not designed to secure perfect combustion when their radiating surfaces are cold. In the State of Ohio during the winter of 1922-23 there were 113 cases of partial asphyxiation and 64 deaths from carbon monoxide poisoning, 46 of the cases and 41 of the deaths being due to gas-fired room heaters.

Above all, however, it is in connection with the automobile that the danger of carbon monoxide poisoning has become most serious. One can scarcely pick up a paper in winter without reading of accidents due to the liberation of carbon monoxide from engines kept running in closed garages. Furthermore, it seems probable that aside from the acute and fatal cases of poisoning there is a widespread chronic intoxication among garage workers and others exposed to this gas. A recent study made by Ciampolini for the State Department of Labor of New York, showed that of 31 garages, 24 showed carbon monoxide in the air, 17 of them in an amount in excess of 0.1% which is set as a danger limit by competent authorities; while of 42 workers in these garages, who were examined physically, 29 showed evidence of carbon monoxide in their blood and many exhibited definite clinical symptoms of carbon monoxide poisoning. Henderson and Haggard believe that even outdoors dangerous concentration of carbon monoxide may be reached under conditions of crowded street traffic. The remedy suggested by these investigators is the equipment of all closed automobiles with a vertical exhaust, discharging above the roof so as to carry the poisonous gases away from the breathing zone outdoors and to discharge them into the range of roof ventilators in the garage. In view of the seriousness of the hazard involved, this policy deserves and is receiving the very serious consideration of health authorities throughout the country.

Odors and Health

The theory that miasmatic vapors of the atmosphere were the chief causes of epidemic disease dates back to the days when Hippocrates lighted fires in the streets of Athens to purify the air and put a stop to the plague. This view peristed as a dominant factor in medical teaching for 1 500 years, and when the medical faculty of Paris reported on the epidemic of plague which ravaged that city in 1348, they attributed the disease as Hippocrates did, primarily to malign conjunctions of the planets and, secondarily and immediately, to a corrupted atmosphere. A free translation of one paragraph of this famous document would read somewhat as follows:

"Although there is danger of pestilential sickness from corrupted water and food as is observed in times of famine and drought, yet there is greater danger of sickness from the corruption of the atmosphere. For bad air is more injurious than food or drink on account of the velocity with which it penetrates to heart and lungs with its evil qualities. We believe that the present epidemic or plague arises immediately from air not only qualitatively altered but corrupted in its substance. By this I mean that normal air existing in its clear and pure state cannot decay or become corrupted unless from the admixture of evil vapors.

"Because therefore many corrupt vapors from the aforesaid conjunction from earth and water have been raised up and disseminated through the air by the blasts of the heavy and turbid southerly winds, on account of extraneous humid vapors which they bring or have brought with them, the air itself has become corrupted. Air thus corrupted necessarily penetrating to the heart corrupts the substance of the heart according to its nature, and decays the surrounding tissues in similar manner, finally according to nature extends and corrupts the principle of life. This is the immediate cause of the present epidemic."

Even fifty years ago it was still held that such diseases as typhoid fever and cholera were pythogenic in origin, that is, that their causative miasms were generated by the decomposition of organic filth. Murchison, one of the leading physicians of his time, taught in 1873 that such fevers "may be generated independently of a previous case by fermentation of fœcal, and perhaps other forms of organic matter" and that in these diseases "the poison is not like that of smallpox, given off from the body in a virulent form, but is developed by the decomposition of the excreta after their discharge." Dr. John H. Griscom, of New York, writing in 1854 displays an even more exact knowledge of the etiology of such diseases. He says*, on what authority the speaker knows not:

"Dr. Carmichael Smith discovered that the vapors of nitrous acid neutralize and render harmless the typhus miasm, which he ascertained to be sulphuret of ammonia, and on the utility of this discovery being duly tested and confirmed, a sum of 5 000 pounds was voted to him by the British Parliament, as a national donation."

The development of the science of bacteriology gradually dispelled these miasms which certainly existed as corrupting influences in the thoughts of men even if they did not influence their physical health; and to-day it is known that the communicable diseases are no more influenced by atmospheric vapors than by the conjunctions of the stars. The fear of noxious odors is, however, very deeply implanted in human psychology and even after the germ theory was well established the old terror persisted under a new guise—that of the alleged predisposing influence of organic emanations—morbific matter, anthropotoxin—in the atmosphere. The physiologist, Brown-Sèquard, was perhaps the most famous proponent of this theory but all efforts to demonstrate the presence of subtle organic poisons in air vitiated by organic decomposition have for the present failed.

The ordinary effects of the air of a badly ventilated room, as has been pointed out, have been clearly shown to be due to physical rather than chemical factors. Fortunately, however, we are safeguarded from a too arbitrary and dogmatic dismissal of the whole problem of bad smells to the limbo of chimeras by the experiments of the New York State Commission on Ventilation; and it is always a relief to find at least some experimental justification for widely held beliefs, since empirical opinion is so likely to prove itself in the long run not without justification. These New York studies indicated that the stale air of an occupied room, even when artificially controlled from the standpoint of temperature and humidity, did have two slight but distinctly meas-

* "The Uses and Abuses of Air," 1854.

urable effects upon human behavior. Subjects exposed to such stale air showed a definite disinclination to physical activity accomplishing 9% less work in stale than in fresh air; and they showed a marked diminution in appetite, the quantity of food eaten at luncheon served in the stale air being from 4 to 14% less than in fresh air of the same temperature and humidity. Experiments in the laboratories at Yale University have similarly shown that the growth of young guinea pigs is quite definitely retarded by exposure to the odors from decomposing organic matter.

As to the discomfort and at least minor derangements of health produced by more highly concentrated odors there can of course be no question. The most exhaustive study of this problem with which the speaker is familiar is contained in a "Special Report of the Rhode Island State Board of Health on the Cause, Prevalence and Effect of Offensive Odors in Providence, Cranston, East Providence, and Warwick during 1921." The odors in question were produced by the burning of high sulfur fuel oils and by the distillation and refining of petroleum. Their influence extended for distances of 3 to 4 miles from the plants at which they originated and was felt by a population of 126 000 people. Record was obtained of definite symptoms affecting 96 persons, such as irritation of the throat, suffocation or choking sensation, nausea, headache, dizziness, and malaise, reasonably attributed to the odors in question. Mr. Stephen DeM. Gage, the Chemist and Engineer in charge of this investigation, discusses the situation as follows, in a passage which deserves much wider publicity than that attained by the usual State report:

"When our investigation was first started certain physicians and public health men with whom we discussed the matter expressed the opinion that the subject of offensive odors was not a health matter; that the effect, if any, was purely psychological. This is largely a question of the interpretation placed on the term health. With a very few exceptions the symptoms of the cases cited in the previous pages were temporary and not lasting. But, while the effect lasted, it was very real and in certain cases sufficiently severe to incapacitate the victim and of sufficient duration to interfere seriously with his regular avocation. In other words it reduced his mental and physical efficiency for a greater or less period of time at intervals which were dependent on the frequency of recurrence of the odors. It is well recognized by physiologists that intense and offensive ordors may cause reflex actions affecting the nervous, digestive, and the secretory systems. Such reactions frequently repeated cannot help but have an unfavorable effect on the general health. Even if the effect is psychological rather than physiological, if the effects produced upon the system are the same, the ultimate effect on the health must be the same.

"From the results of our own investigation we know that there are at least 96 persons who are or have been more or less seriously affected by these odors. From physicians have been received reports of 32 persons made ill and of 15 persons suffering from other diseases whose illness has been aggravated and perhaps their chance of recovery lessened from this cause. All or nearly all of these persons show a record of symptoms identical in character with those known to be caused by fumes or vapors of certain substances which from all available evidence are probable constituents of the odors which these persons have been forced to breath at least a material portion of the time for a period of many months. The consensus of opinion among Rhode Island physicians, as expressed in their replies to our inquiry, is to the effect not

only that the course of a number of diseases may be unfavorably affected by certain of the constituents of these odors, but also that the effect of these odors or fumes would be prejudicial to the continued good health of normal persons."

It may be concluded, therefore, that although polluted air does not bear the germs of disease and does not carry with it mysterious and specific organic poisons, an atmosphere laden with offensive odors is not only objectionable on æsthetic and economic grounds, but under certain circumstances may constitute a real menace to the public health.

It is of primary importance, therefore, that sewage and garbage disposal plants, packing houses, and oil refineries should be designed and operated so as to minimize the discharge into the atmosphere of products of organic decomposition or of offensive fumes from the combustion and handling of odoriferous materials. The task is exceedingly difficult when one is dealing with such substances as hydrogen sulfide which the nose can detect when present to the extent of 1 gramme in 1 000 000 000 000 cu. cm. of air, or as mercapton which is detected twenty-five times more readily than hydrogen sulfide. In the selection of processes for the disposal of sewage and garbage the possibility of aerial nuisance must always be a determining factor; and where the production of offensive odors is unavoidable, the possibility of deodorization by the use of chlorine or in some other way should be given the most careful consideration.

The Rôle of the Engineer in Promoting the Purity of the Atmosphere

In bringing this somewhat lengthy dissertation to a close, the speaker would point out that success in the effort to maintain a pure atmosphere under the difficult conditions of urban civilization depends on the co-operative effort of engineering experts of all the various types represented in the Society, and is not merely the affair of the Sanitary Engineering Division alone.

It is for the sanitary engineer to conduct intensive studies of the odor nuisance problem such as Mr. Gage has made at Providence, to determine the source and nature of the odors at work, their range of influence, and their effect upon health. It is primarily for him, also, to see that sewage and garbage plants, which are among the most prolific sources of complaint, are designed and operated with a minimum of resulting nuisance.

For the control of odors from industrial plants, however, the sanitary engineer will often be forced to call in the chemical engineer, either to re-arrange processes so as to diminish odor elimination, or to destroy the odors before they are discharged into the atmosphere by chemical means.

For the protection of the industrial worker against toxic fumes and dust and against the deadly influence of siliceous particles, the ventilating engineer must design special local exhaust systems, and it is to the heating and ventilating engineer—educated in the newer physiology and freed from the fetish of 30 cu. ft. per min.—that the public must look for the maintenance of comfortable air conditions in schools, offices, churches, theaters, and other places of assembly.

The mechanical engineer can help in the task of promoting atmospheric purity by the provision of automatic stokers and smoke consumers. Even the

electrical engineer has his physiological functions. The speaker can see no evidence that the ozone he offers as an adjunct to ventilation is of the slightest value; but his ultra-violet rays are indispensable in every well-equipped hospital.

Finally, even the railroad engineer and the highway engineer must come into the picture, for the problem of securing fresh air and sunlight for the dweller in great cities is a problem which can only be solved by intelligent town planning and by the skilful use of transit facilities which shall distribute urban populations over a wide area.

In a dozen different ways a thing so common as "the air we breathe" must be safeguarded and controlled by the watchful hand of applied science. Thus only can truth, which as engineers and scientists we serve, free all mankind from the shackles of preventable disease and death.

LAWS RELATING TO OBNOXIOUS ODORS*

By Irving I. Goldsmith,† Esq.

The problem of safeguarding health and preserving the comfortable enjoyment of property is becoming increasingly complex. While remedies grow more efficient, standards mount higher and new dangers are added by commercial and industrial development and the steady influx of population from rural districts to urban centers. The topic under consideration concerns the contamination of the air. Possibly no single natural right is more closely related to the preservation of health, the enjoyment of life, and the comfortable occupation of property than the privilege to breathe clear, pure, and wholesome air. Although modern medicine and science justify and demand relief from conditions which tend to pollute the air, it was anciently recognized that malodorous fumes and stenches impaired health and disturbed the enjoyment of property. Early legal protection was confined largely to the effect of such contamination upon the enjoyment of property, but as far back as Coke's time, the common law had extended its protection to the public in a limited way.

The law relating to the suppression of dangerous and distasteful fumes and gases is found in that division of substantive law known as "nuisance". According to Blackstone, a nuisance is "anything done to the hurt or annoyance of the lands, tenements or hereditaments of another". The present conception of nuisance is broader, however, and "is anything that works an injury, harm or prejudice to an individual or the public."‡ Nuisances are generally known as private and public:

"They are private when the injury resulting from them violates only private rights and produces damage to a few persons only; or even to one person only. They are public when they violate public rights, and produce a common injury; when they injure or annoy that portion of the public which necessarily comes in contact with them."

There is a third class called mixed nuisances "which are both public and private in their effects—public, because they violate public rights, and injure many persons, or all the community; and private, in that they also produce special injury to private rights."

Again, there is a classification as to the nature of nuisances:

"First, those which in their nature are nuisances *per se* or are so denounced by the common law or by statute; second, those which in their nature are not nuisances, but may become so by reason of their locality, surroundings, or the manner in which they may be conducted, managed, etc.; third,

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‡ Definitions taken from "Ruling Case Law", Vol. 20, pp. 380, 383.

those which in their nature may be nuisances, but as to which there may be honest differences of opinion in impartial minds. If an instrumentality or condition is a nuisance at all times and under all circumstances, irrespective of location or surroundings, it is said to be a 'nuisance *per se*'."

These definitions cover the basic law governing nuisances. The rules are of ancient origin in jurisprudence, but they are as responsive to conditions to-day as they were at the time of their conception. The law is progressive and attunes itself with the onward march of civilization. The unitiated, the impatient, and the radical frequently dub the law as reactionary; but their judgment is based upon either lack of knowledge or wilful blindness. Legal reasoning does follow established principles and honored precedents, but the decisions of the high Courts of to-day are undisputed proof of the flexibility of these dogmas in meeting current needs. The Chief Justice of the great Court of Appeals of New York State recently said:*

"I shall follow the thought that administration of the law is a practical matter and that where possible, it must with reasonable flexibility adjust itself to new and changing conditions and, in accordance with recognized principles, must attempt to solve the problems of life in a well-ordered, fair and reasonable way which will secure the approval of well informed and intelligent opinion."

And, pursuing the same subject further, he said:

"In somewhat general terms, we may safely define progressiveness in accordance with generally accepted concepts as a disposition on the part of the Courts toward liberal interpretation of remedial statutes to the end of accomplishing the purposes for which they were enacted; a disposition toward that interpretation, extension, and, if necessary, modification of legal rules and precedents so far as permissible which will secure what the sensible and well informed student would regard as a greater measure of justice between private litigants; and a liberal, but justifiable and faithful, interpretation of Constitutional provisions in the direction of upholding the legislative function to adopt enactments for the greater protection and welfare of the public."

The legal principles governing the regulation and suppression of nuisances from the earliest days of the common law, have constantly yielded to the exigencies of progress, and the limited application to property rights has been developed to cover the broader rights of the individual as typified by the public. The subject assigned to the speaker relates to pollution of the air and this discussion will be confined to those offenses in the category of nuisances which render the air unwholesome and unsanitary and constitute a menace to health and the reasonable and peaceable enjoyment of property. It is evident that, in a paper of this character, only broad general principles can be considered and the distinctions and differences so common to the law must be passed over with the comment that they exist.

The early cases involving private rights pertained very largely to the noxious odors emanating from pig sties and other animal enclosures, vaults and privies, and from such commercial enterprises as kilns, smelters, coke ovens, and apothecaries. These structures or trades have not generally been considered nuisances *per se* because they constituted an essential part of domestic life and business activities; but objectional and deleterious odors emanating from

* *Cornell Law Quarterly*, Vol. 9, No. 4, p. 371.

these sources have always been held to be actionable and, if sufficiently harmful, subject to injunctive relief in equity. The law in this respect has been established for centuries and has been particularly well summarized in a leading case of the United States Supreme Court:*

"There is no doubt of the general proposition that a man may do what he will with his own, but his right is subordinate to another, which finds expression in the familiar maxim: *sic utere tuo ut alienum non laedas.* His right to erect what he pleases upon his own land will not justify him in maintaining a nuisance, or in carrying on a business or trade that is offensive to his neighbors. Ever since Aldred's case, 9 Coke, 57, it has been the settled law, both of this country and of England, that a man has no right to maintain a structure upon his own land, which, by reason of disgusting smells, loud or unusual noises, thick smoke, noxious vapors, the jarring of machinery or the unwarrantable collection of flies, renders the occupancy of adjoining property dangerous, intolerable or even uncomfortable to its tenants. No person maintaining such a nuisance can shelter himself behind the sanctity of private property."

Although the growth of community life and the development of industrial activities have created new conditions which often menace the health and comfort of the occupants of adjoining premises, the Courts have continued to extend the rule cited to these situations for the protection of neighboring property and the occupants thereof.

Of course, it must be borne in mind that an owner of land is always entitled to the reasonable use of his premises and if damage results to his neighbor from such use it is not actionable. Probably the contamination of the air by soot and gases resulting from the burning of soft coal presents the most vivid example of the effects of modern industry when conducted in or near a village or city. The New York Courts were called upon to enjoin such a nuisance almost twenty years ago and held that in the case before it the burning of soft coal was not necessary for the practical running of the plant and constituted an unreasonable use of the manufacturer's property.† The facts are interesting in defining the scope of the case. It appears that the plant in question was located on the outskirts of a village of 13 000 inhabitants in a sparsely settled neighborhood, but one suitable for residential purposes. The nearest dwelling was owned and occupied by the plaintiff and was distant 840 ft. When the wind was in the right direction, the soot and gases from the defendant's plant settled upon the premises of the plaintiff, causing discomfort and slight discoloration of the residence property. The proof disclosed that hard coal could be used to operate the plant, although the expense would be greater. Under these circumstances, the Court awarded damages to the plaintiff and enjoined the defendant from further operating its plant with soft coal. This case created wide comment at the time of its determination as the damage proved was quite inconsequential, but it firmly established the rule in New York State that no one may make an unreasonable use of his property to the injury of his neighbor. The Court, in its opinion, discusses private nuisances as follows:

* Camfield *vs.* United States, 167 U. S., 518, 522.
† McCarty *vs.* Natural Carbonic Gas Co., 189 N. Y., 40.

"The law relating to private nuisances is a law of degree and usually turns on the question of fact whether the use is reasonable or not under all the circumstances. No hard and fast rule controls the subject, for a use that is reasonable under one set of facts would be unreasonable under another. Whether the use of property to carry on a lawful business, which creates smoke or noxious gases in excessive quantities, amounts to a nuisance depends on the facts of each particular case. (21 Am. and Eng. Ency. of Law, 2d ed. 692.) Location, priority of occupation and the fact that the injury is only occasional are not conclusive, but are to be considered in connection with all the evidence and the inference drawn from all the facts proved whether the controlling fact exists that the use is unreasonable. If that fact is found, a nuisance is established and the plaintiff is entitled to relief in some form. Unless the fact is found, or it is an inference of law from other facts found, no nuisance is established, even if the plaintiff shows that he has suffered some damage, annoyance and injury. Those evils are at times incidental to civilized life and the sufferer finds compensation in the arts and agencies of civilized society. What is reasonable is sometimes a question of law and at others a question of fact. When it depends upon an inference from peculiar, numerous or complicated circumstances it is usually a question of fact. Whether the use of property by one person is reasonable, with reference to the comfortable enjoyment of his own property by another, generally depends upon many and varied facts; such as location, nature of the use, character of the neighborhood, extent and frequency of the injury, the effect on the enjoyment of life, health and property and the like."

And, further, referring particularly to the nuisance created by the smoke:

"The defendant's business is lawful and not a nuisance *per se,* although it has been found that as carried on it is a nuisance in fact. The extent more than the nature of the injury, the *quantum,* rather than the *damnum,* constitutes the nuisance. Some smoke is generally created by the natural and ordinary use of land near a village or city, and while this may sometimes be annoying to neighbors it is part of the price paid for living where there are neighbors. But when the smoke is so unusual and excessive as to materially interfere with the ordinary comfort of human existence, the trier of the facts, taking into account all the circumstances, such as public utility, locality, immediate surroundings and the like, may find the use unreasonable. This is not a case where the defendant cannot carry on its business without injury to neighboring property, for all damage can be avoided by the use of hard coal, as is done by one of its competitors in the same kind of business in the same locality, or possibly by the use of some modern appliance such as a smoke consumer, although either would involve an increase in expense. It is better, however, that profits should be somewhat reduced when he did not *come to the nuisance* but was there before. 'The safety of property generally is superior in right to a particular use of a single piece of property by its owner. It renders the enjoyment of all property more secure by preventing such use of one piece by one man as may injure all his neighbors' (Sullivan *vs.* Dunham, 161 N. Y. 290, 300)."

This case has been dealt with at length because it so clearly sets forth the law relating to private nuisance caused by carrying on a lawful business, and also because it deals particularly with the burning of soft coal which undoubtedly constitutes the most pronounced nuisance in populous communities.

Like the law relating to private nuisances, that governing public nuisances has its origin in the common law. Blackstone defines public nuisances as "offenses against the public order or economical regimen of the State, being

either the doing of a thing to the annoyance of the King's subjects or the neglecting to do a thing which the common good requires."* According to current decisions a public nuisance exists whenever a common or public right is invaded.† The annoyance must affect a substantial number of persons in order to constitute it a common or public nuisance.‡ Public nuisances for the most part are concerned with the broader and larger common rights, although frequently a public nuisance may also become a private one when special damage is inflicted upon the individual in the occupation of his premises.§ In illustration, a stable may be so negligently maintained in a well settled neighborhood that the entire community suffers discomfort from the disgusting odors emitted and, at the same time, the occupants of adjacent premises may suffer special damage by being denied the comfortable enjoyment of their property.

A public nuisance, as its character indicates, is indictable‖ and may even be enjoined or abated.¶

Although public nuisances have long been recognized by the common law, it is probably a fair statement that to-day most of the invasions of common rights are characterized by statute or ordinance as public nuisances. This does not signify that statutes and ordinances comprehend all acts which constitute public nuisances, but they usually include those acts which are most likely to impair common rights. Neither does it mean that every act declared by the legislature or municipal government to be a public nuisance will receive that construction when reviewed by the Courts.** Even when legislative or local governing bodies have declared certain acts to be nuisances, such acts must be in fact nuisances known in the law.††

The effect of the legislative or municipal declaration is to eliminate any question of the resulting injury being a common one, but it does not make an unlawful act lawful.‡‡ When the determination rests upon particular facts, and they present a question fairly debatable, the judgment of the legislature will usually be adopted and confirmed.§§

The right to brand certain acts as public nuisances by statute or ordinance rests in the police power of the State. The law is well settled that legislation for the protection of the health, morals, and welfare of the people is a proper exercise of the police power of the State. The validity of such statutes intended to suppress noxious odors was challenged in the famous "Slaughter House Cases" and sustained by the United States Supreme Court.‖‖ The cases merit special comment. In 1899 the Legislature of the State of Louisiana

* 4 Com. 166.

† Jones *vs.* State, 38 Okla. 218; 132 Pac. 319.

‡ Flynn *vs.* Butler, 189 Mass. 377, 386; *in re* Debs, 158 U. S. 564.

§ Quinn *vs.* Lowell Electric Light Corp., 140 Mass. 106; Acme Fertilizer Co. *vs.* State, 34 Ind. App. 358; 72 N. E. 1037.

‖ Commonwealth *vs.* Packard, 185 Mass. 64, 66.

¶ Delaware Division Canal Co. *vs.* Com., 60 Pa. St. 367.

** Lawton *vs.* Steele, 152 U. S. 133, 140.

†† Jones *vs.* State (*supra*).

‡‡ Commonwealth *vs.* Boston, 97 Mass. 555; Richards *vs.* Washington Terminal Co., 233 U. S. 546.

§§ Hadacheck *vs.* Sebastion, 239 U. S. 394.

‖‖ Slaughter House Cases, 16 Wallace, 61.

by statute provided that the business of slaughtering all animals in the City of New Orleans should be confined to certain restricted areas and granted to a particular corporation the exclusive privilege to erect and maintain slaughter houses to carry on this trade and the right to exact fees for this service, prohibiting all others from erecting and maintaining such structures or engaging in such business. The Court affirmed the judgment of the Legislature that the slaughtering of cattle in a great city constituted a public nuisance and that it was a proper exercise of the police power of the State to locate slaughter houses where health and comfort required. A part of the opinion of this Court is illuminating in defining the scope of public nuisances and the inherent power of the sovereign to prohibit them:

"'Unwholesome trades, slaughter houses, operations offensive to the senses, the deposit of powder, the application of steam power to propel cars, the building with combustible materials and the burial of the dead, may all', says Chancellor Kent (2 Commentaries 340), 'be interdicted by law, in the midst of dense masses of population, on the general and rational principle that every person ought so to use his property as not to injure his neighbors; and that private interests must be made subservient to the general interests of the community.' This is called the police power, and it is declared by Chief Justice Shaw (Commonwealth *vs.* Alger, 7 Cushing, 84) that 'it is much easier to perceive and realize the existence and sources of it than to mark its boundaries, or prescribe limits to its exercise. This power is, and must be from its very nature, incapable of any very exact definition or limitation. Upon it depends the security of social order, the life and health of the citizen, the comfort of an existence in a thickly populated community, the enjoyment of private and social life and the beneficial use of property'. 'It extends', says another eminent judge (Thorpe *vs.* Rutland & Burlington R. R. Co., 27 Vermont 149), 'to the protection of the lives, limbs, health, comfort and quiet of all persons and the protection of all property within the State', * * * and persons and property are subjected to all kinds of restraints and burdens in order to secure the general comfort, health and prosperity of the State. Of the perfect right of the Legislature to do this, no question ever was, or, upon acknowledged general principles, ever can be made, so far as natural persons are concerned."

The police power is very broad. It was even held by an Illinois Court and affirmed in the United States Supreme Court* that where a fertilizer plant was established by Act of the General Assembly, and subsequently a community grew up about the plant, that under a village ordinance to suppress the operation of the plant, a bill in equity to prevent the enforcement of the ordinance would be denied. The pecuniary injury which directly resulted to the company from the stoppage of its works was held no bar to the exercise of the police power of the State.

Statutory regulations to prevent nuisances are less common, however, than local ordinances. The answer is obvious. Most cities and villages in their charters are delegated with power to adopt ordinances for the promotion of the health, safety, and welfare of the community. Inasmuch as conditions are so different in each locality the local governing body is better able to appraise the local situation and to make its rules accordingly. Of course, the

* Fertilizing Company *vs.* Hyde Park, 97 U. S. 659.

grant to the municipality is limited by the language of the charter and probably never includes matters affecting State policy.

Neither the State nor the municipality can make an unlawful act lawful by statute or ordinance. Such action may rob the act of its character as a public nuisance, but if injury results to person or property, the act still constitutes a private nuisance. In this connection reference is called to a case wherein a municipality erected a pumping station in a residential locality, burning soft coal to produce power, thereby damaging the plaintiff's residence. The defense asserted that, in establishing the pumping plant and thereafter operating it, the defendant was exercising a governmental function delegated to it by the State, and, therefore, it was not responsible for the misuser of its delegated power. The Appellate Court affirmed a judgment for the plaintiff on the ground that the delegation of authority must be exercised in conformity with private rights, and if their destruction be involved, in such a case, payment must be made.*

The law has also been clearly stated by the nation's highest tribunal:†

"There are many lawful and necessary occupations which, by the odors they engender, or the noise they create, are nuisances when carried on in the heart of a city, such as the slaughtering of cattle, the training of tallow, the burning of lime, and the like. Their presence near one's dwelling-house would often render it unfit for habitation. It is a wise police regulation, essential to the health and comfort of the inhabitants of a city, that they should be carried on outside of its limits. Slaughter-houses, lime-kilns, and tallow-furnaces, are, therefore, generally removed from the occupied parts of a city, or located beyond its limits. No permission given to conduct such an occupation within the limits of a city would exempt the parties from liability for damages occasioned to others, however carefully they might conduct their business."

It is encouraging that the Courts thoroughly recognize the importance of maintaining the air free from pollution. In a renown case the State of Georgia filed a bill in equity in the United States Supreme Court to restrain a corporation maintaining and operating its plant in the State of Tennessee from permitting noxious odors and gases from escaping therefrom and being carried by the winds over the forests, orchards, and crops of Georgia, causing destruction.‡ In granting the desired relief, the Court wrote:

"It is a fair and reasonable demand on the part of a sovereign that the air over its territory should not be polluted on a great scale by sulphurous acid gas, that the forests on its mountains, be they better or worse, and whatever domestic destruction they have suffered, should not be further destroyed or threatened by the act of persons beyond its control, that the crops and orchards on its hills should not be endangered from the same source."

This case is also noteworthy in that it not only recognizes the jurisdiction of the Federal Courts to entertain in equity the petition of a State in its quasi-sovereign capacity, but it establishes a more liberal system of law where the State is a suitor. As to these features of the case, the opinion reads:

* Gordon *vs.* Village of Silver Creek, 127 App. Div. (N. Y.), 888.
† Baltimore & Potomac R. R. Co. *vs.* Fifth Baptist Church, 108 U. S. 317, 334.
‡ Georgia *vs.* Tennessee Copper Co., 206 U. S. 230, 238.

"This is a suit by a State for an injury to it in its capacity of quasi-sovereign. In that capacity the State has an interest independent of and behind the titles of its citizens, in all the earth and air within its domain. It has the last word as to whether its mountains shall be stripped of their forests and its inhabitants shall breathe pure air. It might have to pay individuals before it could utter that word, but with it remains the final power. * * * Some peculiarities necessarily mark a suit of this kind. If the State has a case at all, it is somewhat more certainly entitled to specific relief than a private party might be. It is not lightly to be required to give up quasi-sovereign rights for pay; and apart from the difficulty of valuing such rights in money, if that be its choice it may insist that an infraction of them shall be stopped. The States by entering the Union did not sink to the position of private owners subject to one system of private law. This Court has not quite the same freedom to balance the harm that will be done by an injunction against that of which the plaintiff complains, that it would have in deciding between two subjects of a single political power."

Upon the foregoing authority, the State of New York through the Attorney General in 1916 instituted actions in equity in the Federal Courts to restrain certain corporations operating in Edgewater, N. J., opposite Riverside Drive, New York, N. Y., from discharging over said city, quantities of noisome and disagreeable smoke, fumes, effluvia, and noxious and poisonous vapors and gases, thereby endangering and injuring the comfort and health of its citizens. These actions were the culmination of investigations conducted by the Health Department of New York State, commencing by order of the Governor in 1908 and carried on almost continuously until the beginning of the litigation. The reports rendered upon these investigations disclosed that, because of the fumes and gases cast over from the New Jersey shore, the air was quite generally badly contaminated over that section of New York bounded by Central Park West and the Hudson River and from 72d to 135th Streets. The State of New York thereupon made demand on the State of New Jersey to abate the nuisance, and, no change in conditions being apparent, the Bill referred to was filed. The defendants named were the Bulls Ferry Chemical Company and the Corn Products Company, but the Barrett Manufacturing Company, Valvoline Oil Company, and General Chemical Company were also contributing to the nuisance. Definite action on the part of the State of New York, strengthened by the decisions of the United States Supreme Court, produced immediate relief.* The defendants asked for delay in order to make arrangements to abate the nuisance and, within a year, the defendants and the other offenders had remodeled their plants and installed new methods of manufacture and mechanical appliances, so that the nuisance was practically abated. The cases were never tried, but it was the force of the law which actually caused the suppression of this notorious nuisance.

The decisions referred to in this discussion indicate that, except where constitutional or property rights outweigh public necessity, the Courts will prevent the pollution of the air either through the inherent power vested in them under the common law or by virtue of legislative mandate. The law seems

* A contributing cause was Chapter 292, Laws of New York 1917, authorizing the forfeiture of the charter of a domestic corporation and the revocation of the certificate of authority of a foreign corporation to conduct its business in New York State whenever it appears that such corporation is maintaining a nuisance.

to be adequate to protect the public welfare and enjoyment of property, but resort to the Courts for relief appears to be on the wane for the reason that the skill and ingenuity of the Engineering Profession are eliminating the causes which contributed so largely to the undesirable and unhealthy odors and vapors permeating the air in and about cities and villages. Modern sewage disposal, septic closets, garbage incinerators, smoke appliances, refuse reducers, and manufacturing methods designed to absorb or eliminate disgusting and obnoxious smoke, gases, and effluvia are making communities cleaner and healthier and removing any reasonable excuse for pollution of the air. To the engineering fraternity great credit is due, as their solution is the elimination of nuisances fouling the air without injury or harm to any one, whereas the suppression of nuisances through law must necessarily cause inconvenience and expense to the parties besides loss of full exercise of liberty and property rights.

METHODS FOR DETERMINING THE ORIGIN, PREVALENCE, AND EFFECT OF OBNOXIOUS ODORS AND THE EVALUATION OF AN ODOR NUISANCE*

By Stephen DeM. Gage,† Esq.

During 1920-21 the writer was commissioned to make an investigation of an alleged nuisance caused by certain oil refining plants in the Metropolitan District of Providence, R. I. In planning this investigation it had to be borne in mind that although it was desirable to obtain as full and complete information as possible on all correlated points, only a very limited appropriation was available for the purpose.

Before starting the investigation, therefore, a search was made through health and sanitary journals and reports to ascertain what methods had been followed in other investigations of similar import. These researches proved of little assistance, however, as descriptions of methods used were omitted from the few reports on odor nuisance investigations that were found. It was necessary, therefore, to rely largely on initiative and to formulate methods of investigation. This paper outlines the writer's idea of how such an investigation should be conducted and points out some of the difficulties which may be met and the manner in which they may be overcome for the guidance of those who may be called upon to conduct a similar investigation.

A complete investigation and report on an odor nuisance should cover the following points:

(1) The origin of the odors, and the cause thereof.
(2) Degree or magnitude of the nuisance. Under this head are included the area and population affection, the frequency and duration of the odor manifestations, and the intensity of the odor at different times and different places.
(3) Effect upon health.
(4) Direct and indirect damage to property.
(5) Remedial measures.

Evaluation of an Odor Nuisance

For purposes of record and also for use in legal proceedings it is desirable to have some means of expressing quantitatively the degree or magnitude of the nuisance caused by odors arising from any specific source. No one will question the fact that an intense odor is more of a nuisance than a mild one.

* Presented at the meeting of the Sanitary Engineering Division, New York, N. Y., January 22, 1925.

† Chf. Chemist and San. Engr., Rhode Island State Board of Health, Providence, R. I.

A faint disagreeable odor which persists over considerable periods of time or which is of frequent occurrence must be considered a greater nuisance than a strong odor which occurs only at long intervals, or which lasts only a few minutes at a time. Furthermore, an odor no matter how offensive it may be, is a nuisance only when there are people to smell it. A strong disagreeable odor which can be smelled by only a small number of people must, therefore, be considered less of a nuisance than an odor of less intensity which spreads out over a large and thickly populated territory. The quantitative expression of the magnitude of the nuisance should therefore include four variables, intensity of odor, frequency of odor, duration of time odor is offensive, and population affected.

If each of these variables be expressed quantitatively, their product should furnish a more representative idea of the magnitude of the nuisance than can be obtained by simply comparing the various figures individually.

The frequency may be represented in such a formula by the number of days the odor occurred in a year or some other stated period. As it is not always convenient to continue odor observations for any fixed period, it is probably better to express frequency as the ratio between the total days when the odor occurred and the total days included in the period of observations.

Duration may readily be represented by the average number of hours per day which the odor lasted.

Population affected might be expressed in direct figures, but in order not to have too many figures in the final result, it is better to express population in thousands.

For odor intensity, there is as yet no generally accepted unit of measurement. This might satisfactorily be expressed as parts per million of hydrogen sulfide or some other substance found to be a common component of a number of different odors, or by a factor representing two or more such substances. This combination of factors may be expressed by the formula:

$$M = \frac{D}{T} \times \frac{H}{T} \times \frac{P}{1\,000} \times I = \frac{D\,H\,P\,I}{1\,000\,T^2}$$

in which,

M = the magnitude of the nuisance;
T = the total days of observation period;
D = the number of days odor was noted;
H = the total hours of odor;
P = the population affected;
I = the average intensity of odor.

In compiling the results obtained in the Providence odor survey, no reliable data on "duration of odor" were available and the records of "intensity of odor" determined by the sense of smell were not considered sufficiently accurate to warrant their being used in a formula in combination with other dissimilar data. It was impossible, therefore, to compute the "magnitude of the nuisance" caused by each source. There were reasonably accurate data on the area and population affected, however, and by combining the daily reports of the special observers with the more or less erratic reports from a considerable

number of volunteer observers, fairly representative figures were obtained on frequency of odor. As at least eight odor-producing sources which were causing more or less of a nuisance were under observation, it was desirable to have some method of expressing the relative degree of the nuisance originating from each source. For this purpose the following simplified formula was used to obtain a semi-quantitative expression of the relative degree of nuisance:

$$N = \frac{P\,D}{100\,T}$$

in which,

N = the degree of nuisance;
P = the population affected;
D = the number of different days on which odor was reported from that source;
T = the total number of days on which odor observations were made.

The value of combining even these incomplete data into a single expression is illustrated by Table 1.

TABLE 1.—Relative Degree of Nuisance Caused in Metropolitan Providence by Odors from Various Sources.

Source of odor.	Total days covered in observation. T.	Number of days odor was observed. D.	Population affected. P.	Relative degree of nuisance. $N = \frac{P\,D}{100\,T}$.
Oil Refinery No. 1	148	53	87 700	288.0
Oil Burning Plant No. 1	158	40	32 650	83.1
Oil Refinery No. 2	121	43	21 200	76.0
Tar Products Manufacturing Plant	158	16	6 800	6.8
Gas-works	148	6	11 100	5.0
Oil Burning Plant No. 2	158	16	2 200	2.2
Slaughter-house	158	6	4 700	1.8
Oil Burning Plant No. 3	158	11	1 850	1.3

Selection of Observers

In determining the source, prevalence, intensity, etc., of an odor nuisance chief reliance should be placed on the observations of trained persons. The reports of complainants are usually so biased that they are likely to be untrustworthy, whereas the reports of volunteer observers are likely to be so erratic or so irregular that no complete record of cause and effect can be deduced from them. Volunteer observers, however, may be used in order to supplement the data obtained by the paid men. In the Providence investigation, complainants and other interested persons were supplied with return envelopes and blank forms on which they were requested to report location, date, and time that odors were prevalent. These reports, although they were of little statistical value, served as a check on the regular observers and were also of considerable assistance in plotting the distribution of odors at certain times.

As the acuteness of the olfactory sense varies widely in different persons, special pains must be taken to insure that reports of different observers are comparable in an investigation of this kind. In selecting observers, care must be taken to obtain men whose sense of smell is reasonably acute, and then to train all these men to record odors of the same intensity in the same manner. In this investigation, there were two men in the department who, through long association, had learned to report odors on waters on the same base. All observers were trained by these men in methods of expressing odor intensity. As the investigation progressed, the work of each observer was checked at intervals by one of these men, and, in addition, two or more observers were occasionally sent out together in order that they might check each other.

Vagaries of Odor Characteristics

In attempting to trace odors back to their source, due regard must be given the fact that there may be a decided change in the characteristics of the odor with varying dilution. This variation in character proved for a time particularly troublesome in the Providence investigation. In one section a distinct odor resembling scorched sugar was at first attributed to a large bakery located near-by, but was eventually proved to be derived from the incomplete combustion of oil high in sulfur at a power plant some distance away. Near their source, these same odors when strong smelled like rotten eggs or hydrogen sulfide, whereas at a little distance they resembled burning rubber. The reason for these varying characteristics could not be determined. Probably these particular odors were a mixture of different substances some of which were more overpowering or had greater carrying properties than others. It is well known that some apparently simple odors change materially with dilution and that a blend may have entirely different properties from any of its components.

Peculiarities of Odor Travel

Knowledge of the conditions affecting odor travel is far from complete and peculiarities will frequently be observed which are difficult or impossible to explain. If there is little or no wind, odors usually travel very slowly from their point of origin. On the other hand a strong wind appears to dissipate them. In the experience of the writer an odor nuisance is most likely to occur under the condition of what are generally known as light airs, that is, at times when the velocity of the wind is between 5 and 15 miles per hour. In the Providence survey, an odor was observed in only one instance when the recorded wind velocity was more than 25 miles per hour, and in only nine instances when the wind velocity was greater than 20 miles per hour. In some instances odors travel high and at other times with apparently similar conditions they may travel low. In one instance an odor was traced from hilltop to hilltop for some distance, but could not be detected in the intervening valleys. In certain instances an odor settled in what was probably an air pocket and remained a source of offense for some time after it had ceased to be produced at its source, this condition generally occurring when there was some fog and little wind. Strong odors were also observed on the wind blowing up certain streets while parallel streets only a block distant were prac-

tically free from odor. Such apparent freaks of odor travel may have been caused by differences in air currents or humidity produced by relatively small variations in topographical or other surface conditions. Variations of this kind, especially when they are of regular occurrence, may lead to wide differences of opinion among residents of different parts of an odor-affected area as to whether a nuisance does or does not exist. For this reason all such peculiarities should be noted in an odor survey together with all the concomitant facts by which they may be explained.

Use of Meteorological Records

At this time it may not be out of place to record a word of caution about the use of official Weather Bureau meteorological records. The accuracy of these records cannot be questioned and it is not the purpose of the writer to cast any aspersions upon the men who make the meteorological observations. It must be borne in mind, however, that the stations at which they are obtained are at a specific point usually at an elevation and that the records apply only to conditions at that point.

During the Providence odor survey good use was made of official records of wind direction and velocity in checking up reports of odor at times when the paid observers were not on duty. In many cases, however, the reports of the observers in sections within four or five miles of the Providence Weather Bureau Station were at variance with the official record. The Providence station is on the top of a sixteen-story building in the heart of the city, whereas the observers were on the ground. Under the conditions which prevailed when the odor nuisances were most prevalent, that is, when the wind velocity was low, the ground currents, especially in urban districts, are likely to be very different from those which prevail at an elevation of 100 to 200 ft. The writer has frequently noticed wind blowing from one direction in one street when in another street only a few hundred feet distant, the direction of the wind was entirely opposite. In many cases observers in districts three or four miles apart would report wind blowing from diametrically opposite points of the compass. There is no question that air currents on the ground may vary in direction from those which prevail at a slight elevation. It is these ground currents, however, which govern the movements of odors.

Humidity is another factor which undoubtedly affects odor travel and considerable variations in humidity may exist at a time of light airs in sections which are relatively close together. The presence of water surfaces in the vicinity undoubtedly affects not only humidity conditions, but also the direction of ground currents during the night. It is possible that tidal movements may also have more or less effect on these ground currents. In the Providence survey it was observed that the direction of the wind often changed at about the same time that the tide turned.

Determination of Odor Intensity

For the purpose of recording odor intensities in the Providence studies, the terms "very faint", "faint", "distinct", "strong", and "very strong", were used.

These terms may be defined as follows: A "very faint" odor is one which would be observed by some persons, but would pass unnoticed by the majority. A "faint odor" would be detected by the majority and would be disagreeable to a few. A "distinct" odor is one which would be distinctly noticeable to almost everybody and would be disagreeable to the majority. A "strong" odor is one which would be objectionable to practically everybody. A "very strong" odor would be decidedly objectionable to all except those with a defective sense of smell.

Records of odors described in this manner are very useful for comparative purposes, but cannot be readily used as a basis for mathematical expression of odor intensity.

As a matter of convenience odors of water are frequently expressed by the numerals, 1 to 5, inclusive, a "very faint" odor being recorded by the figure, 1, and a "very srtong" odor by the figure, 5. For lack of a more accurate method these numbers are sometimes averaged to obtain some idea of the mean odor intensity during a stated period. It is apparent from the results obtained by Allinson and Katz in their studies of stench producers, that the concentration of odor judged by the olfactory senses is not proportionate to the amounts of odoriferous substances actually present in the air at the time. There is, therefore, no real basis for assuming that a "faint" or "number 2" odor is twice as intense, or that a "distinct" odor is three times as strong as a "very faint" or "number 1" odor. In fact, there is some basis for the assumption that when dealing with simple odoriferous substances the mathematical ratio between these five degrees of olfactory sensation is geometric rather than arithmetic. When dealing with compound odors caused by two or more substances, however, it is quite probable that these ratios may vary considerably, depending upon the nature of the stench producers present.

There is need for exact analytical methods for determining the amounts of stench-producing substances in air. Unfortunately, the amounts of such substances required to cause offensive odors are extremely small and their detection and accurate measurement require the examination of very large volumes of air. For this reason the collection of samples in bottles or gas bags as is customary for ordinary purposes of gas analysis is not practicable. The practice of drawing or forcing the air through the test solution, as used in some types of air-analysis apparatus, is also impracticable for field work owing to the fact that air movement through the absorbtive medium must proceed very slowly and a rather lengthy stop at each sampling point is thus required when large volumes of air must be examined.

Recently, attempts have been made to adapt to purposes of chemical air analysis the apparatus devised by Palmer of the New York State Ventilation Commission for collecting the dust from considerable volumes of air. In this apparatus the liquid used as an absorbent is broken into a fine spray by the inflowing air and conditions are thus made favorable for absorbtion of the gaseous ingredients from the air. In operation, the air flow through the absorption bulb is maintained by a small motor-driven fan, measurement

of volume being obtained by passing the air through a standard orifice under constant pressure.

The great advantage of this form of apparatus is that large volumes of air can be passed through it in a relatively short time, thereby permitting the determination of extremely minute quantities of gaseous and other ingredients. Weston used this apparatus in his investigations at Fall River, Mass., and reports that small amounts of H_2S and other sulfides could be determined with reasonable accuracy. The chief objection to the apparatus in its present form is that the motor requires the use of 110-volt current which limits its use to points where connections can be made with the domestic lighting circuit. It has occurred to the writer that if the motor were wound to be operated by current from a storage battery, the apparatus could then be used at any point which could be reached in a motor car, and possibly the battery charge could be maintained from the generator of the starting and lighting system. Weston's assumption was that the foul smell of the odors which he was studying was largely due to hydrogen sulfide or other sulfur compounds. It is quite possible that this assumption may also be true of obnoxious odors from sewage treatment plants and perhaps other sources. There is no reason, however, why many other chemical ingredients of air should not be determined by the use of the Palmer apparatus. Knowledge of the chemistry of odors, particularly those that are obnoxious, is very meager and there is a broad field for research work to determine what chemical substances are present and to provide suitable methods for their estimation. As has already been stated, the measurement of odors by the olfactory sense is far from accurate, and methods for exact measurements of intensity are necessary if odor surveys are to be placed on a definite basis.

Determination of Prevalence of Odors

The determination of the prevalence or frequency of odors in order that the nuisance caused may be evaluated by the formula previously given necessitates that a sufficient number of observers be on duty to cover the affected district at all hours of the day and night. A man in an automobile with windshield and windows open can make odor observations at frequent intervals over a considerable territory. It may be objected that exhaust odors from the automobile may tend to cause errors in the observations, but if the car is driven at a fair rate of speed, the exhaust odors are left so far behind that they have no practical effect. In the Providence investigation, the observers traveled on bicycles in order to avoid this theoretical error, but in a supplementary investigation made by Dr. Chapin, Health Officer of Providence, the use of motor cars was found to be a distinct advantage.

Information as to the prevalence of odors in various parts of the odor-affected districts was derived both from observations made each night by regular employees and from reports sent in from time to time by volunteer observers living in those districts. Whenever possible, the regular employees traced odors which they noted to their source of origin, and from their reports it was possible to determine both the total frequency of odor during the middle night hours, and the relative responsibility of the odor-producing sources.

The reports of the volunteer observers served as a check on the reports of the regular observers and also furnished information as to the occurrence of odors at other times than those when the regular observers were on duty. As might be expected, reports from volunteers were received at irregular intervals when the visitation of odors was especially marked, and except in one or two instances no attempt was made by these observers to keep a complete record of the occurrence or non-occurrence of odor. In many of these reports it was stated that odors came from certain specified sources, although as a rule the volunteer observer did not trace the source of odor. However, the probable source of odor reported by volunteers could frequently be estimated by a study of the direction of the wind at the time and comparison with other contemporary reports. The volunteer reports, therefore, although of relatively small value individually, did furnish collective evidence of the frequency of odors which proved to be of considerable statistical value.

Determination of Affected Area and Population

There are often times when obnoxious odors are much more intense and affect a much wider area than usual and a special effort should be made to determine the spread of odor under the particular conditions of wind and weather which prevail at such times.

In the Providence investigation, a number of special surveys were made to determine the limits of the territory affected by odors at particular times. The method used was to follow the odor in one direction as far as it could be detected and to record this point. The car was then run some distance farther and turned back toward the odor area, and the point at which the odor could again be detected was recorded. After running well into the odor area and recording the odor intensity at various points, another turn was made and the odor limit at another point was determined. This procedure was repeated until a sufficient number of points had been determined to permit the odor-affected area to be plotted accurately on the map, together with data as to odor intensity at various places. By running outside the odor area at frequent intervals the sense of smell of the observers was revivified and the car freed from odors, thus facilitating the determination of the limits of the odor-affected area and the distance of odor travel.

Theoretically, the area which may be affected by odors from any source is a circle the radius of which is the maximum travel distance of the odors from that source. Owing to the effect of prevailing winds, topographical conditions, and other factors which are not clearly understood, odors usually travel farther in certain directions than in others. The map of the area actually affected, therefore, is likely to be irregular in shape, with a large proportion on one side of the odor source. By platting all the locations at which odors have been noted at various times on a map of the affected sections, diagrams can be made showing the total area subject to influence from any source, and this area can then be measured. In computing the extent of such areas, water surfaces should usually be eliminated, because in a study of this kind, it is the land surfaces with which one is principally concerned. If the same territory is subject to visitation of odors from two or

more sources, separate plots should be made of the area affected by each odor source. Maps with the affected areas blocked out furnish a picture of the effect of any odor-producing source which can be obtained in no other way, and are invaluable, both as a matter of record and as evidence in case action through the Courts is necessary.

From a nuisance view point, it is the population of an odor-affected district, rather than the area itself which is of major importance. There are a number of ways by which the population of such an area can be estimated with reasonable accuracy. When a house-to-house canvass is made for any purpose as part of the investigation, the number of inhabitants in each house should be ascertained and recorded as a basis for a population count. When it is not feasible to obtain a direct population count recourse must be had to estimates. When the area affected is residential, and not too large in size, a count of the number of houses can be made. Two persons, in an automobile, can cover a considerable territory in a few hours counting and recording the number of houses on each side of the various streets. In such a count, the object is to determine the number of families and a two-family house should be counted as two. Even in closely populated tenement or apartment districts, a close count of the number of families can quickly be obtained in this manner. In some cases, the original street by street data obtained in a special census are available, or the local tax assessors have data which can be used. In a good residential district or in a high-class apartment district it is usual to assume that the average family consists of four persons, but in closely built tenement districts this factor should be increased to five, and in densely populated sections occupied largely by people of foreign birth the factor may be six or even more persons per family. In many communities an enumeration of children of school age in each school district is made every year, and knowing the ratio of school children to total population, a fair estimation of the population of any section can be made from such data. In Providence, where the affected areas were large and thickly populated, and where the influence of various odor sources frequently overlapped, the population estimates were based on the counts obtained by enumerators in different districts in the census of 1920. In arriving at these estimates, the odor-affected and the census enumeration districts were both plotted on the same map. After blocking out territory known to be uninhabitated, the proportionate part of the census district which lay within and without the odor-affected district was then determined with a planimeter and the census population distributed accordingly. The total population of the odor-affected area, obtained by adding the sectional figures as determined by the method described, was then corrected for the presumed increase in population since the census was taken. In this method of computation it was necessary to assume an even distribution of population within the inhabited portions of the border-line enumeration districts, and also that growth of population was the same in all such districts. In a few selected localities the population estimated by this method was checked by a house or family count and the figures obtained by the two methods were found to be in reasonably close agreement.

When the odor-affected area contains factories and large mercantile establishments the employees of which are subjected to the odors during working hours, the average number of such employees should be ascertained and a correction made in the total population affected. This is contrary to census enumeration practice in which only resident population is counted in order to avoid duplication. In an odor survey, however, it is probably fair to assume that approximately half the employed population lives outside the odor-affected area, but as these people are subjected to the odors during working hours they should be included in the estimate of population affected.

Effect on Health

Although it is generally admitted that chemical fumes emanating from various industrial processes may cause illness and even death, it is a disputed point as to whether offensive odors *per se* can actually be considered unhealthy. Nevertheless, the claim will usually be made by complainants that their health is being unfavorably affected by offensive odors and it may also be claimed that the symptoms of persons ill from other causes are being seriously aggravated as a result of the nuisance and that their recovery is thereby being delayed or prevented. For these reasons, therefore, an investigation of a major odor nuisance cannot be considered complete until all the facts bearing on its possible effect on health have been collected and correlated. This part of the investigation should be carried out by a physician or at least by one who has had sufficient training in physiology and public health to determine to what extent the symptoms of illness are psychological and to what extent they are actually physical.

Information relating to the health phase may be obtained by a house-to-house inquiry throughout the odor-affected district or by inquiry only among persons who are reported to have been made ill. Frequently an inquiry in one family where illness of this kind is reported will bring forth information about members of other families who have been similarly affected. When feasible the house-to-house canvass is preferable as it is thus possible to obtain definite statistics as to the proportion of the population in whom symptoms of illness are being produced. The inquiry among residents should be supplemented by an inquiry among physicians practising in the affected area to obtain all possible information as to the effect of the odors on patients under their care. If by chance there should be a hospital in the odor area, an effort should be made to enlist the aid of the hospital authorities in the investigation to the end that the effect of odor visitations on various patients may be noted and made a part of the case history. In studying the health phase of this question and particularly in making inquiries among both physicians and laymen, it must be constantly kept in mind that definite facts and not opinions are desired and also that to the layman nausea, sick headache, vertigo, malaise, etc., are real illnesses, irrespective of whether the cause is physical or psychological.

Injury to Property

It has long been recognized by the Courts that property damage may be caused by odors or fumes. Injury of this kind may be either direct or indirect.

Direct injury to property may result from damage to buildings, household furnishings, etc., or to trees, shrubbery and other vegetation. Indirect injury may result from the fact that owing to the existence of a nuisance and the feeling of the people that the locality is unhealthy the property becomes less desirable as a residence or work place and its sale value is therefore depreciated. Although direct or indirect property damage is often considered outside the jurisdiction of sanitary authorities, proof of its existence is valuable as an argument to induce the owner of the source from which the odors or fumes originate to take measures to abate the nuisance. In an odor survey, therefore, it is wise to collect and record all obtainable information concerning both direct and indirect injury to property.

When buildings which have been painted with lead or zinc paints are exposed to fumes containing any appreciable amounts of sulfides, discoloration is likely to ensue. This action is usually more rapid on freshly painted surfaces. Household silver, automobile fittings, etc., may also be tarnished by sulfides. Complaints of such troubles, which at first may seem impossible, on investigation will often bring out information of a surprising nature. Information as to damage to paint may also be obtained by inquiry among master painters and paint dealers. Exposure to acid fumes may affect vegetation more or less seriously and also cause rapid deterioration of sheet metal, textile fabrics, paper, etc. Sometimes inquiry among roofers and sheet metal workers will yield information regarding excessive corrosion of metal roofs, conductor pipes, cornices, etc. Damage to trees can readily be detected by inspection in summer, either by discoloration and withering of foliage or by premature falling of the leaves. As not all vegetation is affected alike, care must be used before a report is made that such damage does not exist.

Indirect injury to property by depreciation of value is somewhat more difficult to estimate. When a nuisance has been of long duration, its effect may sometimes be observed by comparison of changes in valuation in property in different sections on the books of the tax assessors. Information about changing property values may often be obtained from real estate brokers. The financial aspect of a major odor nuisance is usually not appreciated either by city and town officials or by the public. As practically the entire revenue of the community is derived from taxes assessed on property, any material reduction in taxable valuation in one section must be compensated either by increased valuation in other sections or by a general increase in the tax rate. Every taxpayer in the community is, therefore, affected irrespective of whether or not he owns property in the nuisance area, and the presentation of the financial evidence of this nature can be used to influence public sentiment outside the odor-affected area in cases when municipal authorities are slow to take necessary action.

Remedies

This paper has dealt only with methods which may be followed in determining the cause, scope, and effect of an odor nuisance with the object of presenting all the facts clearly and forcibly to the Court or other official body which may be called upon to abate the nuisance. In order that such a report

may be constructive, rather than destructive, the investigation should also include a study of the conditions which prevail in the industrial plant or other source where the offensive odors originate, particularly to ascertain whether the emission of odors cannot be eliminated by changes in the processes or in the plant or whether the offensive character of the odors or fumes cannot be overcome by some method of treatment.

The scope of this paper does not include a discussion of methods of odor elimination. Suffice to say in closing, however, that an industry or other source which is the cause of a major odor nuisance is usually also a financial asset to the community in or near which it is located, and although it is not justifiable to consider such a nuisance as a necessary evil, it certainly is not justifiable to close down such a plant when the nuisance may be abated by the application of remedial measures.

ELIMINATION OF ODORS FROM GARBAGE DISPOSAL WORKS*

By Samuel A. Greeley,† M. Am. Soc. C. E.

General

The disposal of garbage is an operation in which an odor hazard must be fairly recognized. Unless garbage disposal works are designed, built, and operated with care, odors may result. In fact, with some methods of disposal, odors are likely to result unless the design and operation are good. In this regard, garbage disposal is somewhat akin to the odor-producing industries such as tanneries, packing houses, glue works, oil refineries, rendering plants, etc. Measures for odor elimination thus become pertinent.

A number of factors influence the general problem of the elimination of odors from garbage disposal works, one of which centers about the environment. In some locations, some odors apparently are not objectionable. In other locations, the same or less intensive odors might cause a nuisance. In recognition of this fact, the zoning map of Kansas City, Mo., indicates areas where odor-producing industries may be located.

Another factor is the cost of operation. Both construction and operating costs may be increased as odors are eliminated. If the disposal is by reduction, rates of drier operation may have to be curtailed and processes adopted for odor elimination which do not produce additional revenue and which add to the cost of disposal. If it is done by incineration, additional fuel, larger capacities, and sturdier construction may be required.

Other factors relate to the many phases of garbage disposal as a municipal enterprise, including group habits and viewpoints, the efficiency of the operating staff, the financial resources and budget allowances, competitive conditions in the field of garbage plant installations, patent limitations, etc. All these factors are closely interwoven. Local considerations are often justly important and cannot be entirely discarded. A helpful perspective may be secured by describing a few actual conditions.

In Rochester, N. Y., a garbage reduction plant of the most approved design as regards odor elimination is operated in a commercial and semi-industrial district near the center of the city. A similar plant was built on Staten Island, New York, in relatively open country, but not far from residential districts. The protests against this plant were sufficiently vigorous practically to force its abandonment shortly after it was built. The City of New York,

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†Pearse, Greeley & Hansen, Chicago, Ill.

however, operates an incinerator in a commercial district only a few blocks from residence and business sections. In two or three other cities, garbage reduction works are in such isolated locations that apparently reduction with less odor control and lower operating costs is permissible. Thus, from a practical standpoint, the attitude of the community, the relative economies of near-by or distant location, and the over-all costs of disposal by various processes must be considered and carefully balanced.

Status of Odor Elimination

Relatively little progress in the development of methods for odor elimination can be recorded with tangible results expressed in definite terms. Inside feeding has been developed at hog farms, but capacities and designs are not generally understood and applied; and too little attention has been paid to the sanitary disposal of the unconsumed garbage and the hog manure. Fume-consuming grates have been proposed for incinerators and the danger of low temperatures has been commonly recognized, but many designs fail to consider needed capacities for grates, flues, and other parts of the incinerator under peak conditions. At reduction works, odorous gases have been washed with water and chlorinated, with a reduction of odors, but methods of applying the water and chlorine to secure the best efficiencies need further development.

It is apparent that the subject of odor elimination from garbage disposal needs technical study and development with a fuller realization on the part of those purchasing garbage plants that the odor problem is vastly important and is likely largely to control the capacity, arrangement, and cost of the works under design. In this paper the writer hopes to visualize the subject more clearly than has been done heretofore, to outline its fundamental aspects, to suggest means of odor elimination, and to stimulate further progress.

Fundamental Considerations

The problem of eliminating odors from garbage disposal works should not be entirely confined to methods of elimination after the odors have been produced. It is a fundamental consideration that odors which are difficult and costly to eliminate should be prevented or reduced as much as possible. The old adage as to the value of prevention before cure is true in this case. However, both the prevention and the cure should be studied and a well-balanced procedure developed with due regard to efficiency and cost.

There appears to be no common scale for determining permissible odor and, therefore, the location and environment of a garbage plant may be considered in the general scheme for odor elimination, although they affect the nuisance resulting from the odor rather than the odor itself. For instance, if it should be necessary in a town to burn garbage, night soil, screenings, or other such refuse materials with an additional fuel, it may be said that the elimination of odors bears a major relationship to the temperature of combustion and, therefore, to the quantity and cost of additional fuel. In this case, is it better to locate the plant far afield, involving an additional haulage cost, but a lower fuel cost, permissible through a somewhat lower temperature standard?

Thus, a fundamental consideration is the standard of odor elimination required or desirable in each locality. In a general way and speaking in practical terms, odors should be eliminated; but it is of the utmost importance that the economic and essential relationship be realized between the type of plant, its capacity and arrangement, and its location, on the one hand, and the degree of odor elimination and its cost on the other. A straight Cobwell reduction plant is likely to produce less odors requiring elimination than a modified Cobwell or Cobwell-Merz plant in which the drier gases are added to those of the reducers, but the straight Cobwell plant is likely to cost more. The cost and efficiency of odor-eliminating devices thus become pertinent.

Terms Used

It is not necessary in this paper to define at length the terms used. The paper relates primarily to odors from garbage works. Other classes of municipal refuse such as ashes, rubbish, manure, street refuse, etc., are included only as they enter the garbage disposal problem. Garbage is here used to mean the animal and vegetable waste matter originating in houses, kitchens, restaurants, and hotels, and includes the natural content of moisture, and generally, also, the tin cans in which portions of the food were originally supplied.

Of the various methods of garbage disposal, special reference will be made to disposal by feeding to hogs, by incineration, and by reduction, as these terms are used in the broader sense to mean the process used rather than a particular patented device or arrangement. Hog-feeding and the reduction method are applicable to garbage only, but most refuse materials may be disposed of by incineration.

Comments on Odors

Garbage odors should be characterized or classified so as best to promote and facilitate a study of their elimination, as follows:

1.—Garbage odors as related to the food materials comprised, such as cinnamon, coffee, lemon, burnt meat, and many others. Such odors are characteristic of fresh garbage and might be termed the "fresh garbage" odors. Their predominance is relatively brief, depending on the condition of the garbage after its house treatment, the frequency of collection, and similar factors.

2.—The odors of decomposition. In warm weather, for instance, moist garbage decomposes quite readily with the production of odors which are more or less of a nuisance depending on the character of decomposition. Garbage which is wrapped and drained in the kitchen or mixed with ashes decomposes more slowly than otherwise. Odors from decomposing garbage may come from dirty collection wagons and disposal works.

3.—The process odors, an expression here used to include those odors which result from the various methods of garbage disposal and at times are more or less characteristic of them. Such odors are the "pig pen" odor, the odor of incomplete combustion, the odor of drier gases, etc.

Among these odors, some may be classed as pleasant and others as offensive. Some will be intermittent and others more or less continuous; and some may

be seasonal. The odors of decomposition are, perhaps, likely to be more offensive, but less widely distributed than those from gases discharged from a chimney top.

Although this paper is not on the subject of odors, but rather on their elimination, it should be noted that scientific information about odors, *per se*, is likely to help materially in developing improved methods of odor elimination. Much of interest has been published on the subject of odors proper, such as the interesting paper* by Louis L. Tribus, M. Am. Soc. C. E., and the several discussions of it. The following quotation† is of interest:

"The common belief that the olfactory stimulus consists of minute material particles suspended in the air current of the olfactory organ is supported by the observation that odors may be carried on the wind in a definite direction many miles. Odors do not emanate from a given center and disperse in all directions as sound and light do. Moreover, many substances, such as arsenic, that are odorless under ordinary circumstances, give out an odor after they have been heated sufficiently to volatilize. The fact, discovered in 1917 by Woodrow and Karpman, that the adaptation time for olfaction—the time needed for an olfactory sensation to wane completely—is directly proportional to the vapor tension of the odorous material shows that olfactory stimulation is due to the activity of gaseous particles. These and other like observations have led to the conclusion, now generally accepted, that the olfactory organs are normally stimulated by material particles, and not by disturbances of a non-material character.

"Some odorous bodies, such as musk, are well known to give out these material particles for a very considerable time without appreciably changing weight. From the standpoint of a receptor this indicates that olfaction is called forth by an infinitesimally small amount of substance, and measurements directed toward testing this question justify the conclusion. These measurements have been made in a variety of ways."

Facts about the chemical and physical characteristics of odors and odor-producing substances, although relatively meager in the garbage field, are, however, of considerable import in a study of odor elimination. Thus, Parker suggests that certain olfactory stimuli are more soluble in oil than in water and that, in fact, solubility in oil may be "of much more significance for olfactory stimulation than solubility in water". This further suggests that "scrubbing" gases from garbage plants with oil as well as water might prove advantageous.

Parker also indicates that olfaction is essentially a chemical process and that some progress has been made in discovering relations between chemical structure and olfactory sensation. Thus, "* * * in a general way types of chemical constitution can be indicated for the six groups of odors that he [Henning] was able to distinguish. * * * In the burnt odors, the ring is smooth as in pyridin, and in the foul odors the ring is fragmentary as in cacodyl". These comments and quotations are stimulating and show the possibilities before engineers in the understanding of the odor-elimination problem.

* "Odors and Their Travel Habits," *Transactions*, Am. Soc. C. E., Vol. LXXXV (1922), p. 378.

† "Smell, Taste and Allied Senses in the Vertebrates," by George Howard Parker, 1922, p. 49.

Sources of Odors in Garbage Works

The sources and causes of odors in garbage works may be related to the several parts of the works as follows:

(*a*).—*The House Treatment.*—Odors may come from accumulations of garbage in the can or house receptacle and from accumulated piles of garbage spilled from the can. In some apartment houses, the garbage is spouted to the ground and these spouts may become foul.

(*b*).—*The Collection.*—If the collection wagons are not cleaned, or are difficult to clean, they may become quite odorous. Leaky and overloaded wagons may spread odor-producing material along the route. A proper covering of collection units is desirable and may be important.

(*c*).—*The Transportation.*—In cases of long haul, the garbage may be transported from a transfer station to the disposal works in scows, freight cars, or large trucks. Poorly designed and maintained transfer stations with inadequate facilities for washing are likely to produce odors. Such conditions may be aggravated if the garbage is not removed from the transfer station frequently.

(*d*).—*The Final Disposal.*—Garbage disposal works may cause odors through design and construction in the first place and neglectful operation in the second place. Such factors as the capacity and general arrangements of the plant are important.

To secure relative freedom from odors, these several sources should be appreciated and operations conducted to prevent odors as described more fully subsequently.

Effect of House Treatment

Local odors may result from poor house treatment and odors may be spread along collection routes if the interval between collections is too long, especially in warm weather. If the house receptacles are not cans with good covers, but are baskets, boxes, or barrels, they may leak and foul the ground on which they stand, or they may overflow, if they are too small. Local odors may result. A good method is to have the garbage drained and wrapped before it is placed in the can, but this method is not generally applicable to disposal by reduction or hog-feeding. It is practiced in Minneapolis, Minn., Milwaukee, Wis., Trenton, N. J., and elsewhere, and it facilitates incineration. In Madison, Wis., the garbage is wrapped by the housekeeper and then unwrapped at the hog farm before feeding, at a cost estimated at $2 500 per year. This, however, may result in a fresher garbage at the hog farm.

Effect of Collection

Unclean garbage wagons will carry odors along their route. Such odors are noticeable 100 ft. or more from the wagons. They can be eliminated by the selection of a type of wagon easily cleaned, with a good cover, and by washing the wagon at regular and sufficiently frequent intervals. A good type of cover is of canvas arched over the top of the wagon and arranged in sections which can be thrown back during filling.

The European practice is to wash the wagons every day and this practice is growing in the United States, particularly during the summer months. Washing the wagons on alternate days will materially reduce odors, but will not eliminate them. With only two washings a week, odors are likely to develop. At Milwaukee, the estimated cost at pre-war prices of having a man scrub wagons with water and a broom was about 4 or 5 cents per wagon.

Odors in the collection wagons and in disposal works will be reduced if the garbage is collected at sufficiently frequent intervals. A common practice in this country is to collect once a week in winter and twice a week in summer, but this is hardly sufficient, and a collection every other day in summer is often desirable. In some cities, especially in England and Europe, garbage is collected daily at least from the business districts. This is a good practice if the garbage is to be fed to hogs. Additional collections add materially to the cost but they are often justified by the better service to housekeepers. If a collection unit can visit 250 houses in a working day, each unit will serve 750 houses with two collections per week, and with less garbage per collection probably somewhat more than 500 houses with three collections per week. Thus, more units will be required to make the more frequent collections, entailing an increased cost of less than 50% during the period of more frequent collections.

The collection of garbage, ashes, and rubbish mixed is practiced abroad and to some extent in this country. From the standpoint of odor elimination it is a good practice, but it limits disposal to mixed incineration except where sanitary fill may be possible. If dumps for ash disposal are relatively easy of access, mixed collection is likely to cost more than separate collection, because the former requires a more frequent collection of ashes than householders ordinarily require.

Effect of Disposal

Elimination of odors from garbage disposal works centers chiefly about the disposal plants proper. The sources of such odors may be stated as follows:

(*a*).—Odors from the raw garbage and its storage and handling about the plant. If the plant capacities are such that garbage must be stored at the plant for several days during peak seasons, odors will result. The age of the garbage as delivered to the plant also affects the odor situation. Lime, creosote, and other cleansing and deodorizing substances may be used to advantage. Provision should also be made for cleaning and washing the plant.

(*b*).—Odors may come from the processes. Thus, in hog farms, an incomplete disposal of hog manure and unconsumed garbage may cause serious odor troubles. At incinerating plants, incomplete combustion may permit odorous gases to escape from the chimney top. In the reduction process odors may come from the vapors escaping from open grease-skimming tanks, from hot materials when exposed, and from leaks about piping and tanks. Odors may also come from the digester vent gases and from the drier gases.

(*c*).—Some odors may come from the products of disposal, as, for instance, half burned garbage from incinerators delivered to ash dumps; or the accumulation of tankage, tailings, and sewage at a reduction plant.

The extent of odors from garbage disposal works is influenced more than is realized by details of design and construction. In Reduction Plant A, for instance, floors may be of concrete, piping may be easily kept tight, the capacity may be sufficient so that no garbage is held in storage, there may be sufficient driers so that scorching and burning of the garbage is negligible, and the plant as a whole may be kept clean and in good repair. Contrast such a situation with Reduction Plant B, where floors are rough and uneven, where in the summer heavy deliveries of garbage may be stored at the plant for several days, where inconvenient arrangement renders pipe maintenance difficult, where driers are forced to operate at high temperatures, and where slovenliness prevails. The elimination of residual odors is likely to be much more difficult at Plant B than at Plant A.

Composition of Garbage and the Gases from Disposal

Little appears of record as to the characteristics and quantities of the gas and odor-producing components of garbage. Most of the analytical data relate to the composition of the garbage as regards incineration, reduction, or feeding to hogs. Thus, an average analysis of garbage in Washington, D. C., for 1915 is given in Table 1.

TABLE 1.

Item.	Percentage by weight.
Moisture	73.80
Combustible	22.50
Ash	3.63
Ether extract	5.12
Potash, as K_2O	0.28
Phosphoric acid, as P_2O_5	0.39
Nitrogen	0.71

An average analysis of garbage in New York, N. Y., from dry composite samples taken in 1905 and 1906 is given in Table 2.

TABLE 2.

Item.	Percentage by weight, dry basis.
Carbon	43.10
Hydrogen	6.24
Nitrogen	3.70
Oxygen	27.74
Silica	7.56
Iron oxide and alumina	0.41
Lime	4.26
Magnesia	0.28
Phosphoric acid	1.47
Carbonic acid	0.59
Lead	0.20
Tin	Trace sulfides
Alkalies and undetermined	4.45

Analyses of the products of combustion of mixed refuse incinerators have been made to determine the CO_2 in the chimney gases, but few have been made with garbage alone. Analyses have also been made of gaseous products from

garbage reduction plants. The report on the elimination of odors from the Barren Island Disposal Plants (Osborn, 1915), furnishes data for the digester vent gases, as given in Table 3.

TABLE 3.

Item.	Percentage before entering condenser.	Percentage After Passing Through Condenser.	
		A	B
Carbon dioxide.....	45.2	36.8	6.2
Oxygen.....	10.8	11.8	18.0
Sulfur compounds.....	Present	Present	Present

In addition, the following constituents were found to be present: Alcohols, acetic acid, fatty acids, fats, essential oils, and aldehydes.

Samples of the drier gases were found to contain 6.2 to 5.1% of carbon dioxide, 12.6 to 14.9% of oxygen, and 2.2 to 1.2% of carbon monoxide. No sulfur dioxide was found in the drier gases, but acrolein and similar compounds were indicated.

It is likely that more analytical data would be helpful in approaching the odor problem, and very likely more are of record. However, so few are readily available that the foregoing are given in the hope that more will be published. It should be stated, however, that odors may be produced by very minute quantities which might not be shown by an ordinary analysis.

Incineration of Garbage

Odors from incinerating plants probably arise more often from the storage about the plant and from incomplete combustion. There are two general types of incinerators which, in a general way, embrace the various designs, for example, the "outside storage" and the "inside storage" types.

Outside storage incinerators are a development of the mixed refuse incinerators first studied in detail in this country by J. T. Fetherston, M. Am. Soc. C. E., in connection with the installation of two plants on Staten Island, New York, in 1908 and 1913. A considerable volume of technical information is available relating to the operation of this type of plant when burning a mixture of garbage, ashes, and rubbish, and also, but to a less extent, when burning garbage and rubbish only. Rates of burning per square foot of grate area, draft requirements, flue areas, and heat balances are quite well settled. Thus, odors from incomplete combustion can be generally avoided. The outside storage of the garbage makes careful design and operation necessary if odors from this source are to be avoided.

In plants of the inside storage type, a large part of the garbage is dumped into the furnace from the collection units as delivered. Outside storage at the plant is thus largely eliminated. However, steady uniform combustion is more difficult and lower rates of burning appear to be necessary. In this type of plant, safe maximum loadings have not been so definitely fixed for continuous complete combustion for the various designs.

Fig. 1 shows an estimated quantity of coal required per ton of garbage to maintain a temperature of 1 250° Fahr. In this estimate, the composition of the garbage, of the coal, and of the mixture for the yearly average, are given in Table 4.

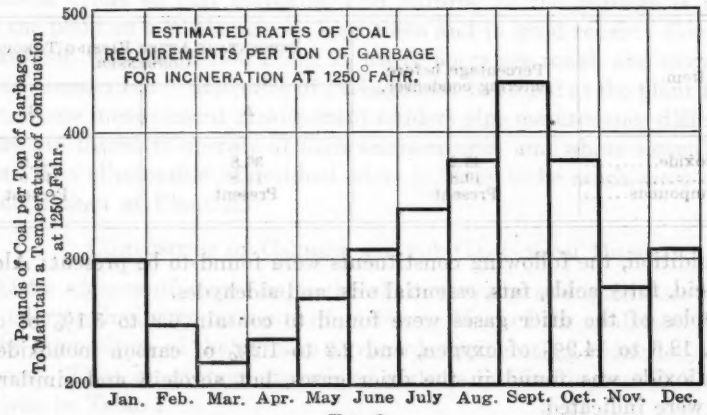
ESTIMATED RATES OF COAL REQUIREMENTS PER TON OF GARBAGE FOR INCINERATION AT 1250° FAHR.
Pounds of Coal per Ton of Garbage To Maintain a Temperature of Combustion at 1250° Fahr.
500
400
300
200
Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

FIG. 1.

Assuming 75% excess air and 20% loss of heat by radiation, this mixture results in a temperature of 1 240° Fahr.

All incinerators should have ample combustion and dust-settling chambers. Lack of such chambers increases the odor hazard and allows dust and sometimes paper to be carried up the stack. The combustion chambers at Milwaukee have capacities equivalent to 15.4 cu. ft. per ton of mixed refuse furnace capacity per 24 hours.

TABLE 4.

Item.	GARBAGE.		COAL.		MIXTURE.	
	Pounds.	Percentage by weight.	Pounds.	Percentage by weight.	Pounds.	Percentage by weight.
Carbon	102	5.09	239	79.62	341	14.8
Hydrogen	61	3.03	14	4.65	75	3.3
Nitrogen	41	2.07	4	1.31	45	2.0
Oxygen	205	10.23	14	4.55	219	9.5
Sulfur	41	2.07	3	1.02	44	1.9
Ash	72	3.61	16	5.39	88	3.8
Water	1 478	73.90	10	3.46	1 488	64.7
Totals	2 000	100.00	300	100.00	2 300	100.0

Satisfactory incineration over a number of years calls for durable construction with properly designed furnace structures to stand the relatively hard service. With leaky furnace fronts, cracked brick work, and inadequate draft control, cold air enters the furnaces and lowers the effective temperature of combustion.

Reduction of Garbage

The development of garbage reduction in this country has been influenced by the odor problem as well as by costs of operation and market conditions. Several groups of reduction processes have resulted, among which may be mentioned the following:

(*a*).—The cooking group, in which the garbage is first cooked by steam in digesters and then generally pressed and percolated for the quite complete recovery of grease, the waste liquor being evaporated and added to the tankage. In some plants, the process is limited by omitting gasoline extraction of grease or the evaporation of waste liquids, or both.

(*b*).—The drying group, in which the garbage is first dried and then percolated for grease recovery with a further processing of the residual solids for tankage. In this process, there is no cooking and the digester vent gases are eliminated.

(*c*).—The Cobwell group, in which the entire process is accomplished in closed tanks termed reducers. In the reducers, the garbage is treated with solvent, heated, dewatered, degreased, and dried. The process thus offers a minimum of odor hazard. Recently, the garbage has first been dried to increase the general plant capacities and to reduce net operating costs.

The so-called Morrison process has been adopted at Indianapolis, Ind., and Dayton, Ohio, for the preparation of a stock and poultry food and other products from garbage. It is a cooking process, using a steam-jacketed digester in which cooking, pressing, and drying are done.

At garbage reduction works several relatively well defined sources of odors have been noted. First are the garbage odors arising from the delivery and storage of the garbage. Second are the digester odors which are commonly described as having a caramel or burnt coffee odor. The odor of the digester vent gases is apparent at times and is different from the digester odors. Third are the drier odors resulting from the escaping drier gases. These generally have a sweet burnt vegetable odor with occasional whiffs which are acrid and irritating. By condensation, by washing with water, by heating to a high temperature, by treating with chlorine gas, and by removal of dust, these various odors have at times been largely eliminated.

A comparative analysis of these various reduction processes as they effect odors involves so many local factors that general typical operating schedules are not likely to be helpful. Obviously, a completely developed plant of the cooking type, requires more different separate operations than one of the drying type. In the former method, the cooked garbage is usually pressed to a cake containing from 55 to 60% of moisture of fairly uniform character, and this cake is passed through driers. Under the latter or drying method, green garbage with an average moisture content about 75% is the material dried. There is, however, a wide range of moisture content in the different particles. Thus, although one process eliminates cooking and pressing, the other calls for heavier work by the driers. Thus, the economies of operation and the likely success of measures for odor elimination are interrelated.

Factors influencing the costs of disposal are fixed charges which reflect the first cost, labor costs, maintenance costs, net sale prices of grease, and tankage after deducting freight, and the cost of odor elimination. This last factor includes the often considerable increase in first cost due to the type of driers, condensers, and other equipment permissible from an odor standpoint, as well as the cost of odor-eliminating devices.

Digester Operation

The cooking of garbage in digesters generates gases and vapors the treatment of which is important in the control of odors. There are a number of different digesters on the market. Some constitute a vertical cylindrical steel tank, generally lined with vitrified brick, with a false bottom over a drain. In these the garbage is cooked with live steam. The period of cooking varies from season to season with the condition of the garbage and, at times, with its age and state of decomposition. A frequent period is 8 to 10 hours. During cooking the excess steam is vented through small pipes to condensers. Some digesters contain arms or paddles which are rotated to stir the garbage during cooking. Water or waste liquors are added to promote the cooking. Other digesters are steam-jacketed and the heat from the jackets cooks the garbage and may be used to evaporate the liquid contents. In other processes, some of the liquids are pressed out by steam and, in some, the pressed material is partly dried by the heat of the steam in the jacket.

The gases and vapors from the digesters usually pass to condensers, where the steam in the vent gases is condensed and a large part of the gases is absorbed by the water. In some plants, the insoluble gases have been trapped and passed into the boiler furnaces, but it has been found that heating these gases to 2 000° Fahr. does not eliminate them, but makes them more irritating by changing the sulfur compounds to sulfur dioxide. When these gases are first condensed and then burned and discharged at the top of the boiler stack, it is probable that air dilution and dispersion is helpful in reducing the odor trouble. Based on studies by Osborn, Crowe, and Klein, it was concluded that by first heating the insoluble digester vent gases to about 1 200° Fahr. and then passing them through water all odors were eliminated. The extent and character of these odors have not been fully related to the condition of the green garbage and to the schedule of operating the digesters.

Drier Operation

As regards odors, the type and design of drier and the rate of firing and of feeding garbage or press cake are important. With direct heat driers in which the gases and flames of the fire pass directly into the drier, charring or burning of the garbage may result from contact between the intensely hot gases and the partly dried material. This is more likely to occur if the feeding of material into the drier is not uniform and if its distribution in traveling through the drier is uneven. Charring is also more likely to occur if there is a poor adjustment of the fire to the quantity of incoming material and to variations in its moisture content from time to time and throughout the mass.

A commercial rating for a direct heat drier, 5½ ft. in diameter by 40 ft. long, is the evaporation of 4 000 lb. of water per hour. In some garbage reduction plants, rates of direct heat drier operation have been noted as given in Table 5.

TABLE 5.

Plant.	Water evaporated, in pounds per hour.	Dimensions, in feet.	Approximate Moisture Content, Percentage by Weight.	
			Incoming material.	Product.
Pittsburgh, Pa.	3 400	6 by 40	60	10
Chicago, Ill.	6 500	5½ by 40	75	10
New Bedford, Mass.	3 000	5½ by 40	75	35

As odors such as acrolein (from burned grease) result from burning or charring the garbage, close control of the drier operation is needed. This requires relatively complete combustion in the furnace so that only hot gases reach the drier. The temperature can be controlled to some extent on the way to the drier by air inlets, brick regenerators, and like factors.

With indirect heat driers, the chance for burning the garbage by direct contact with the flames is reduced as the flames and hot gases from the furnace pass around the outside of the drier shell with the material on the inside. If, however, bits of grease and other substances stick to the hot shell, they will burn. In some driers, the hot gases pass first around the outside of the drier and then through the inside with the material to be dried. Such driers were recommended for the proposed plant at Cleveland, Ohio, and were rated at an evaporation equivalent to about 8.2 lb. of water per pound of coal, which compares favorably with a direct heat drier.

With steam driers, the moisture is driven off by contact of the material with the shell of the drier (or steam tubes through the drier) heated by live steam. Thus, the chances for burning are practically eliminated unless the dry material ignites. The rate of evaporation, however, is low, as steam driers require about twice as much fuel per pound of water evaporated. Steam driers are, therefore, less often used in garbage reduction plants. However, under some circumstances, it may be preferable to operate at a slower drying rate and a higher cost in order to reduce the odor hazard. In some plants, the garbage or press cake is first dried to about 30% moisture in direct heat driers and then finished in steam driers.

Treatment of Drier Gases

Even with the best of design and operation, it is probable that some odors will result from the driers, and these must be eliminated by special treatment. The most common method is by treatment with water, commonly termed scrubbing. The gases are passed through a masonry structure in which sprays or curtains of water are maintained. A large water surface should be exposed to the gases passing through the scrubber. The sprays of water should condense the steam and absorb the soluble gases and carry both to the

sewer. If the velocity of the gases through the scrubber and into the stack is too great, the particles of moisture and some dust will escape at the chimney top, and if insufficient water is used, some of the steam and soluble substances will escape to the atmosphere. Thus, scrubber operation may not be entirely efficient. In scrubber design, the items of temperature, velocity, time, quantity, and exposed surface of water and the general arrangement are pertinent and should be related to the type and rate of operation of the drier.

Dust is probably best removed by sedimentation or centrifuging prior to scrubbing. In some cases, in addition to scrubbing, the drier gases are heated by passing them through the hot gases of a coal, oil, or gas furnace. As a result of the tests at Barren Island, it was stated that "the odor of drier gas can be completely eliminated by heating to a temperature of 1 850° Fahr." Here, again, the cost of heating is pertinent and should be related to the design and operation of the drier and scrubber.

Recently, chlorine gas has been used for the elimination of odors from drier gases under the Henderson-Haggard patents. At New Bedford, Mass., it is estimated that about 1 lb. of chlorine is used per 1 000 000 cu. ft. of drier gases at 100° Fahr. The chlorine is introduced at the entrance to a small scrubber.

Experience with Plant Locations

The selection of sites for garbage disposal works has often been an arduous task, which is apparently more difficult in some cities than in others. Among the more important factors are the following:

(*a*).—The occupancy and use of adjacent areas. Unoccupied and unused areas do not suffer immediate damage from odor-producing industries. Residential districts where people spend their leisure hours and where children are growing up are probably the least desirable districts for locating garbage plants.

(*b*).—The type of disposal plant and the character of its design and construction. The details of the plant may properly be related to its location with due regard to future property developments and plant additions.

(*c*).—The distance to which odors are likely to travel. Odors from digesters and driers in garbage reduction works have been detected at distances of several miles.

A record of plant locations showing the distance from the city hall to the disposal works is given in Table 6. These distances range from a few hundred feet to 50 miles. Some engineers are of the opinion that plants should be located far afield where odor elimination is not required. Others feel that garbage should be disposed of in the community which produces it and in such a manner as to eliminate odors.

General Summary

In odor elimination, attention to detail is the secret of success. Thus, plant upkeep and cleanliness are of great importance. It seems almost axio-

matic and certainly it is common sense, that a clean garbage plant tends to eliminate odors as compared with a dirty one; and yet the condition of garbage disposal plants covers a wide range from very dirty to clean. If plant operators would realize that clean means clean and that there is no compromise with dirt, much odor trouble would be eliminated. Having these points in mind, the following considerations will be helpful in odor elimination:

TABLE 6.—DATA RELATING TO THE LOCATION OF INCINERATORS, NOVEMBER, 1924.

City.	Population, 1920.	Refuse matter handled.	Number of plants.	Miles from business center.	Character of locality.
Atlanta, Ga	200 616	G. R, A.	1	0.75	Railroad yards.
Charleston, W. Va	39 608	G. R.	1	0.75	Semi-residential and commercial.
Dallas, Tex	158 976	G. R.	4	1.5	Factory and residence.
Danville, Ill	33 776	G.	1	....	Negro houses of good character within 500 ft.
Elgin, Ill	27 454	G.	1	0.5	Residences and soap company.
Fort Worth, Tex	106 482	G. R.	4	....	.....
Houston, Tex	138 276	G. R.	3	1.5	.....
Miami, Fla	29 571	G. R.	3	3.0	Residences but none within 500 ft.
Milwaukee, Wis	457 147	.....	1	1.25	Entrance to harbor.
Minneapolis, Minn	380 582	G.	1	4.0	In open country near city workhouse.
New Orleans, La	387 219	.....	2	2.2	.....
Oak Park, Ill	39 858	G.	1	0	Schools, city hall, residences.
Paterson, N. J	135 875	.....	..	....	.....
Philadelphia, Pa	1 823 779	.....	..	2.5	.....
St. Louis, Mo	772 897	.....	..	1.2	Commercial.
San Francisco, Calif	506 676	G. R.	1	....	.....
Savannah, Ga *	83 252	.....	..	....	.....
Scranton, Pa	137 783	.....	1	0.75	Rendering plant and factories.
Springfield, Ill.*	59 182	.....	..	....	Small residences.
Trenton, N. J	119 289	G. R.	1	....	Center of city.

NOTE.—G = Garbage; R = Rubbish; A = Ashes.
* Discontinued.

(*a*).—There should, without doubt, be a good general plan for handling garbage covering the house treatment, the collection, and the final disposal. This will result in a fresher garbage at the disposal works.

(*b*).—As part of the general plan, good house treatment should be developed and the collection frequency oriented to the method of disposal and the location of the disposal plant as well as to the convenience of the householders.

(*c*).—Collection wagons should be regularly cleaned to eliminate odors and to reduce the chances of receiving decomposed garbage at the plant.

(*d*).—Garbage disposal works should be built on suitably chosen sites with reference to the character of disposal works and the over-all costs of garbage collection and disposal.

(*e*).—Of particular importance is the capacity of the garbage disposal plant. No garbage plant should be subject to serious overload when garbage collections are heavy, if odors are to be eliminated. This is a real factor too often not given serious and definite consideration.

(*f*).—Following a good general plan, clean operation and ample real capacity of disposal works suitably located, there should be added proper devices for

the elimination of residual odors, including combustion and dust removal chambers at incinerators and scrubbers, condensers, burners, chlorinators, etc., at reduction works.

To secure these various measures for odor elimination properly calls for the best of technical engineering effort. To facilitate this work many more accurate data, carefully taken and recorded, should be made available on rates and results of operation for all the various devices. However, with proper effort, a practical elimination of odors from garbage disposal works can and should be expected.

Tables 7 and 8 give data relating to garbage reduction plants and garbage hog farms, respectively.

TABLE 7.—DATA RELATING TO THE LOCATION OF GARBAGE REDUCTION PLANTS, NOVEMBER, 1924.

City.	Population, 1920.	Miles from business center.	Character of locality.
Akron, Ohio*	208 435	2.0	Near main highway.
Boston, Mass	748 060	4.0	Island, Boston Harbor.
Bridgeport, Conn	143 555	3.0	.....
Buffalo, N. Y.*	506 775	6.5	.....
Chicago, Ill	2 701 705	4.5	Stockyards.
Cincinnati, Ohio	401 247	6.0	Scattered dwellings.
Cleveland, Ohio	796 841	8.0	Sparsely settled.
Columbus, Ohio	237 031	4.0	Sewage disposal plant in undeveloped district.
Dayton, Ohio	152 559	8.0	Open country.
Detroit, Mich	993 678	20.0	Isolated near main highway.
Dubuque, Iowa	39 141	4.0	Isolated.
Indianapolis, Ind	314 194	3.0	Open country near main highway.
Los Angeles, Calif.*	576 673	2.5	Warehouses.
Michigan City, Ind	19 457	4.0	Near main highway.
New Bedford, Mass.*	121 217	2.5	Sparsely settled.
New York, N. Y.*	5 620 048	12.0	Isolated.
Philadelphia, Pa	1 823 779	2.5	Industrial.
Pittsburgh, Pa	588 343	22.0	Isolated.
Rochester, N. Y	295 750	0.75	Commercial and industrial.
Schenectady, N. Y	88 723	1.2	Mixed.
Syracuse, N. Y	171 717	1.6	Sewage disposal plant.
Toledo, Ohio	243 164	3.5	Stockyards.
Washington, D. C	437 571	35.0	Isolated.

* Discontinued.

TABLE 8.—DATA RELATING TO THE LOCATION OF GARBAGE HOG FARMS, NOVEMBER, 1924.

City.	Population, 1920.	Miles from business center.	Character of locality.
Akron, Ohio	208 435	7	Farms.
Denver, Colo	256 491	7	Near city limits.
Grand Rapids, Mich	137 634	35	Farms.
Lansing, Mich	57 327	3.5	Farms.
Los Angeles, Calif	576 673	50	Open country.
Madison, Wis	38 378	3.4	Near sewage plant in undeveloped district.
Newark, N. J	414 524	2	Commercial and industrial.
Salt Lake City, Utah	118 110	....	.....
Utica, N. Y	94 156	5	Farms.
Worcester, Mass	179 754	3	Developing residential.

CONTROL OF ODORS FROM SEWAGE TREATMENT PLANTS*

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Synopsis.

A study of this subject presupposes a knowledge of the general subject of odors, their nature, production, and means of transport. The writer has had no opportunity for experimental work and, therefore, can treat the subject only in the most general manner. A line of research, however, is suggested which may produce results.

The subject has been studied under the following heads:

Character of Odors
Source of Odors
Control of the Production of Odors
Control of the Escape of Odors
Conclusions

General

Sewage is, at best, water-carried filth, the wastes from the population and culinary and industrial processes. Such material may give off odor, usually unpleasant *per se* and often reminiscent of its source.

A sewage treatment plant handling such wastes may be expected to make its presence known in the immediate neighborhood through the sense of smell, but the necessity of dealing promptly, effectively, and continuously with such matter demands considerable tolerance. Efforts should be directed toward minimizing discomfort, nuisance, and damage, by control of the operating process, by the design of the plant, and by its location. Wherever possible, it should be isolated at a distance from occupied territory and the frequency, direction, and intensity of prevailing winds should also be considered. It should be surrounded by a wide area under municipal ownership or control and preferably be masked or screened by vegetation.

Character of Odors

Just as the odor of fresh feces varies with the food and the condition of the individual's digestion, so when the putrefactive process is continued at a sewage treatment plant, odors will vary with the character and condition of the influent sewage and with the regimen of the continuing processes of bio-chemical change and digestion throughout the plant.

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The principal gases given off by putrefying sewage are methane, carbon dioxide, and hydrogen sulfide. Only the latter possesses appreciable odor. All of them, however, may act as carriers of other odorous material. As an example of this transporting power of gases, pure carbon disulfide has a rather pleasant ethereal odor, but the commercial article carries impurities that give it its well-known smell which is exceedingly disagreeable.

Water vapor may carry gases and other products of the decomposition of organic matter in solution or it may transport such products in colloid form, or in the form of finely divided suspended solids. If these malodorous particles reach human olfactories the fact of the existence of odors is at once established.

Another source of odor is the presence of moulds which reside and grow on walls, floors, hand railings, and all exposed surfaces in the immediate neighborhood of the works. These are readily transmitted by contact with the flesh or clothing. If one touches such surfaces, his hands or gloves will have a noticeable and disagreeable odor for some time thereafter.

Source of Odors

The odor of fresh sewage, when not confined and when flowing tranquilly in channels and tanks or when remaining quiescent in tanks, is not particularly offensive, except to the hypersensitive. As such sewage becomes older, its odor is more pronounced and its condition passes on through the stale to the septic state, when gas can be seen to bubble from the surface and an odor of hydrogen sulfide may be perceptible and also an odor often described as a "sweet-sickish smell." If sewage is confined, as when it flows through an illy-ventilated sewer or chamber, the air may become very foul.

When the influent sewage flows rapidly over steps or down an incline where the smooth flow is broken by baffles—as is or was the case where lime is mixed with the sewage at Worcester, Mass.—in advance of the chemical precipitation tanks, the odors liberated are very strong. A decided cessation or reduction in intensity of odor is observed at this station as one proceeds along the walk between the tanks, but it again becomes intense on going back to the vicinity of the lime mixer.

Trash from coarse racks, if not complicated by the presence of offal or dead animals, can ordinarily be removed, and disinfected, burned, dried, or covered before foul odors are noticeable.

Detritus or grit from properly operating grit chambers does not emit unpleasant odors, as it contains little putrescible matter. If, however, sludge is allowed to collect in such chambers and remain and become septic, it may give rise to smells.

Fine racks and screens which intercept feces, or places where feces are present in large quantities floating in the screen chamber or accumulated in piles, may become offensive, as noticed in the screen house at Baltimore, Md. If such material arrives at the plant already comminuted, or if visible pieces are so few that it is practicable to break them with a hose stream and pass the fragments on with the effluent, the remaining screenings may vary from washed out garbage and offal to non-putrescible detritus and will only be

seriously offensive if not promptly removed and disinfected, burned, dried, or covered.

The odor from sewage in a properly operated Imhoff sedimentation chamber is, as described, dependent on the freshness of the sewage. In a septic tank, however, where the sewage is generally older and where there is a mass of undigested sludge, both below the surface in the tank and floating on the liquid, there is usually a more disagreeable odor from the undigested sludge. This condition is best met by covering the tanks. When sludge is placed in tanks for separate digestion, the odor is more intense and becomes nauseating to many.

The effluent of an Imhoff tank when sprayed upon a sprinkling filter will be more or less odorous, depending on whether it is stale or fresh, concentrated or dilute. It may also be affected by the character of the raw sewage and by the thoroughness of the preliminary operations.

When the sprinklers are in display the odor is noticeable to the leeward, as might be expected. When the sprinklers are at rest and the bed is in good condition little odor is noticeable if sufficient sedimentation has been previously accomplished. If, however, proper sedimentation has not been performed, fragments of putrescible matter of considerable size may lodge on the surface of the bed and form accumulations which will putrefy and give off odors. With proper preliminary sedimentation, the smaller sized particles of suspended matter will pass through and below the surface of the bed and the air entrained by the falling drops will carry down any odors given off by such particles. Moreover, such particles themselves will be washed down into and through the bed.

In the activated sludge process, little odor is occasioned by the aeration tanks. In the direct oxidation process, as the electrolytic tanks are kept closed, little odor may be anticipated except at the screening plant, for the sewage before passing into the sedimentation tanks has been treated with an excess of lime, which also prevents odors from being given off by the sludge.

Thoroughly oxidized effluent from a sprinkling filter and in a final settling basin has no appreciable odor, but the secondary sludge when occasionally removed and allowed to stand until the larvæ and worms contained therein have died and their bodies have putrefied, is sometimes quite offensive for a few days. It has an odor similar to that of a bait box of fish worms which has been neglected until the worms have died from exposure to the sun and lack of nourishment.

Well digested sludge has a not unpleasant musty odor which does not travel far. Some describe it as a "choky odor", or as if it were occasioned by a fine dust.

Control of the Production of Odors

Screenings should be removed promptly and covered with earth. The value of composted screenings as a fertilizer has been suggested. A continuous belt-conveyor has been used at the Irondequoit Treatment Plant at Rochester, N. Y., since 1917 for removing the product of four 12-ft. Reinsch-Wurl screens. The belt dumps the screenings into an industrial car which is hauled

out when full. The cleanest method of removal is probably by pneumatic conveyor. By this method the screenings are least exposed to the air and to flies.

The writer has a plan for a plant soon to be constructed in which the only treatment of the sanitary sewage will be multiple screening. It is proposed, after passing coarse racks, to screen the fresh sewage twice through openings of diminishing size and then to convey the screenings, including feces, and grit if any, to the top of a closed silo tank for storage. They will later be discharged from the bottom of the tank into farmers' trucks when required.

Raw sewage and sewage in tanks and channels should be screened or skimmed so that no floating material will be present to putrefy on the surface. Bio-chemical changes in the sewage solids can best take place under water for gas rising through the water will be washed and partly dissolved so that less will be sent abroad into the atmosphere.

If the design of the channels is such that sewage will flow smoothly and not be broken up and vaporized, considerable odor will be avoided. If the design allows spray to be blown into the air, it may be condensed by providing a covering on which the spray may impinge.

Sprinkling filters have been rejected for some exposed locations near dwellings, and contact beds have been constructed rather than the sprinkling filters, because of the fear of odors to the lee of the filters. In such situations, advantage might be taken of the economy of the trickling filter over the contact bed by adopting a dripping distributor in place of the usual sprinklers which toss the spray into the air and thus furnish the most cause for complaint as to odors. Wherever possible a location should be sought which is not exposed to winds which may blow odors or flies to a distance. Sludge is more or less offensive as it is less or more thoroughly digested.

Separate sludge digestion tanks have been operated experimentally with a layer of oil to keep air from the surface and solids from exposure on the surfaces. The experiments have not yet been conclusive. As a general proposition, sludge digested under water is less productive of odors than when exposed above water.

Sludge cake from the pressing of undigested sludge is likely to be offensive, especially in warm moist weather. It may be covered with earth or ashes. Digested sludge is inoffensive and does not attract flies.

Lagooning undigested sludge is likely to produce odors, for either scum will form or there will be insufficient water to cover the sludge which will putrefy and give off odors.

In general, lagooning should only be adopted in winter or in remote locations where no nuisance will be occasioned to neighbors. Secondary sludge, following sprinkling filters, may be pumped into tanks for digestion, or removed when the weather is best for its disposal by lagooning.

Control of the Escape of Odors

Assuming that certain odors will be produced in a sewage disposal plant engineers are confronted with the problem of preventing their escape from the plant to the surrounding atmosphere at such intensity and with such

frequency as to constitute a nuisance to persons residing in or passing through adjacent territory.

If it is assumed that odors are volatile emanations, gases, colloids, liquids, or finely divided solids which reach human olfactories, this part of the study must be directed to the means by which these attenuated gases or minute particles move, what gives direction to their motion, and what effects their intensity as observed odors, in various localities.

The elements which at once suggest themselves are:

(*a*) Diffusion of gases and vapors in still air.
(*b*) Relative temperatures of air, sewage, gas, and vapor (convection).
(*c*) Moisture and vapor tension of the atmosphere.
(*d*) Wind direction and intensity.
(*e*) Topography, elevation, and exposure.
(*f*) Screens, natural and artificial.
(*g*) Mingling of other more pleasant odors.
(*h*) Psychic considerations.

(*a*).—If the air is perfectly quiet and there are no disturbing temperature conditions, a gas or a vapor carrying odors may diffuse equally in all directions in the atmosphere, and its intensity will be inversely as the cube of the distance from its source; hence the odor will not travel far.

(*b*).—If, however, the sewage and the gas or vapor emitted by it is warmer than the surrounding air (a condition which may obtain in quiet winter weather), the warm gas or vapor will rise through the cooler and denser atmosphere until the odor-bearing gas or vapor has cooled to the temperature of the surrounding air. During this time diffusion has been taking place into the atmosphere so that one may assume an odoriferous column expanding upward in the shape of a plume, denser at the center than at the periphery and similar in form to the steam cloud above a volcano; not much odor would cause complaint under these conditions.

If, however, the air is warmer than the sewage, as on a summer day, the gas and vapor given off will diffuse into the atmosphere relatively near the ground and only rise and disperse when it has attained the temperature of the air.

The two opposite conditions of temperature just cited may account, in part, for the more intense odor near the disposal plant in summer than in winter, although doubtless there is the further explanation that more active decomposition is taking place in summer than in winter and greater quantities of gas are liberated during the summer.

There is also the case of the cool summer night when the sewage may be warmer than the denser air and warm enough for the maximum of bio-chemical activity. Being slightly warmer than the air, odoriferous gases will rise to some height, but possibly not far enough to be diffused in the upper air as described for quiet winter weather conditions. With a gentle breeze, these summer nights are often made unpleasant at some distance from the disposal plant, for windows are open and residents may be awakened by an unusual and nauseating odor and have their attention concentrated on this manifestation.

(*c*).—If the air is dry it will avidly take up vapor and as it is no respecter of odors, it will take the pleasant and the unpleasant alike. Winds may carry these odors to considerable distance. With moist air, however, near the dew point or when rain is falling, sewage vapors will not be taken up and only gases will be transmitted which are being given off so voluminously that they are not entirely absorbed by the rain or atmospheric vapor.

(*d*).—The condition of absolute quiet is so rare as to be almost theoretical, for there is generally some wind movement, be it ever so slight.

A strong wind will usually dilute the odors to so great an extent that they become negligible at a short distance from the disposal plant.

A gentle breeze, however, wafts the odor cloud bodily to leeward before it has become sufficiently attenuated by diffusion to destroy its unpleasant character. This condition is more noticeable in summer when the disposal plant processes are most active and when, as already mentioned, windows are open. This indicates the advisability of not placing a plant to the windward of a summer population.

(*e*).—If the plant is in a protected valley, or one surrounded on the windward side by woods or high hills, the probability of blowing odors from it is considerably reduced.

(*f*).—Screens of natural forest trees not only prevent access of the winds which transport odors, but both forest trees and artificial plantings of trees and shrubs by means of their moist leaves furnish surfaces on which odoriferous gases and vapors may be condensed or absorbed.

(*g*).—If trees and shrubs which give off pleasant odors are planted about the premises in masses sufficient to affect the atmosphere, they will be noticed at times for their beauty and for their pleasant odors and at other times will serve to disguise unpleasant odors by their presence.

(*h*).—Out of sight is out of mind in sewage plants as in other things. Some citizens who see scum on a river at a distance will think they smell it, when in fact the scum and the stream may be odorless.

Neat and artistic planting about the station where it must be exposed, and screens of trees or shrubbery to hide it if possible, do much to prevent imaginary odors from causing annoyance. The nerve sensation called smell may be forgotten if other interests are paramount.

Conclusions

The sewage disposal plant should be designed liberally so that it will not be overloaded. It should be located in a protected and isolated spot. It should be operated to avoid uncovered, decomposing, solid matter and the walls and floors should be kept clean and washed down at least daily. Splashing and the needless production of vapors should be avoided if possible. The plant should be screened from view when practicable and visible parts should be made attractive by means of trees and flowering shrubs. Keep the sewage treatment plant away from the public and keep the public away from it, especially when it is not functioning properly. These measures will mitigate if not entirely prevent the escape of odors from a plant to the surrounding territory.

A suggested line of research is as follows: As exceedingly minute portions of a substance are carried in the air and constitute odors and as bacteria exist in earth, in sewage, and in the air close above a sewage plant, may it not be conceived that the putrefactive odors which differ from pure gaseous odors are in part, at least, due to the presence of these bacteria in the air?

If this is true, will not the destruction of these bacteria result in the diminution of the odor? Chlorine, the best known disinfectant, would have to be distributed and released continuously in order to be effective, and moreover it would add an odor of its own.

It would seem that engineers might profitably, first, seek for some type of gaseous disinfectant which would be pleasant, or better still, odorless; and, second, devise means for its economical application at the sources of odors in the various parts of a plant.

THE DETECTION AND ELIMINATION OF ODORS FROM OIL REFINERIES*

By Robert Spurr Weston,† M. Am. Soc. C. E.

In a commercial or practical sense, the word, petroleum, applies to natural, liquid hydro-carbons which, from a scientific standpoint, are not strictly liquid, but are mixtures of gases, liquids, and colloidally suspended solids.

Shortly after its discovery, the chief use of petroleum was in the preparation of illuminating oil. Following this occurred the development of petroleum lubricants which were found to be superior to the animal and vegetable fats and oils previously used. However, it is chiefly because of the development of the internal combustion engine and the increased use of oil as fuel that the petroleum industry has become so extensive. It is estimated that there are about 16 000 000 automobiles in use in the United States at present, and the number of Diesel, gasoline, and other motors of this general type is increasing for use on land and water, and the high prices of coal and labor have furthered the use of oil for fuel.

The world's production of petroleum from 1919 to 1923 was as follows:

Year.	Total Number of Barrels.
1919	558 892 000
1920	700 902 700
1921	762 241 000
1922	854 809 000
1923	1 010 995 000

Of the total petroleum produced, more than 60% came from the United States, and more than 90% from the United States and Mexico. The production of petroleum in Mexico is declining, but the loss is likely to be greatly compensated by increased production in Venezuela where extensive fields are being exploited.

With this extensive and increasing production of petroleum, it is not surprising that there has been a great increase in the number of refineries throughout the world. Most of the refineries in the United States are situated along an arc drawn from Texas to Massachusetts, in California, and in Wyoming. Until recently there were no refineries in New England, but in the past few years several large installations have been made in the vicinity of Narragansett Bay and Boston Harbor. The introduction of this new industry in thickly settled regions where the people are jealous of the purity of the

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† Cons. Engr. (Weston & Sampson), Boston, Mass.

atmosphere and the cleanliness of the shore waters, has created new sanitary and æsthetic problems.

The use of petroleum in the various grades is growing and has become general rather than local. Therefore, it must be expected that refineries, which have increased from 176 in 1914 to more than 500 in 1924, will be located where economic conditions necessitate. Consequently, sanitary engineers must assist in making these plants inoffensive and thus contribute to the prosperity of these localities with the minimal impairment of a healthful and salubrious environment.

There are now three large oil refineries in Massachusetts and two in Rhode Island, and it is in these States that vigorous complaints regarding odors have arisen.

The crude petroleum oils differ greatly in composition, specific gravity, and viscosity, but the property that most concerns sanitary engineers is the sulfur content, which varies from less than 0.1% in Pennsylvania oils through less than 0.5% for Mid-Continent oils, to less than 3.0% for Wyoming oils, and to more than 5.0% for Mexican oils. Sulfur is important because it forms disagreeable compounds with the hydrogen, nitrogen, and hydro-carbons in the oils. These compounds, some of them gaseous, are given off during the process of distillation. The most difficult odors to control occur when a refinery is operating with Mexican or other oils high in sulfur. Certain refineries in New England began operations with Mexican oil, and with no devices to prevent the escape of odors. The reaction by the public was instantaneous and violent.

Typical Refinery Practice

Although this paper is not descriptive of oil refining, and although the practice of this art varies greatly, it seems well to outline the general practice in order that the methods of odor control may be understood more readily.

Refineries may be classified in two general groups, namely, skimming or topping plants which confine their operation to the separation of gasoline and the lighter oils from the crude oil, and complete refineries which split the crude product into gasoline, naphtha, kerosene, gas oil, light and heavy lubricating oil, fuel oil, paraffin wax, pitch, coke, and other products, as the markets demand. There are many modifications of these two kinds of plant. For example, either may be operated in conjunction with a so-called high temperature distillation or cracking plant which, through heat and pressure, splits off hydro-carbons of lower boiling point from heavier oils, that the yield of the more profitable gasoline and lighter products may be increased. Then again, it is unprofitable for certain refineries to carry the distillation until only coke remains in the stills, and such may stop distillation when the residue in the still is suitable for fuel, or, carried further, is a semi-solid pitch or petroleum asphalt.

Figs. 1 and 2, show the flow sheet for a complete refinery and the main features of a crude oil distillation plant, respectively. Although the kinds of distillate from the still are numerous, this paper concerns itself chiefly with the lighter products, some of which may escape from the refinery in

gaseous form, and the heavier oils, pitch or coke, which, when hot, are likely to give off strong odors. Coke cooled with water is apt to emit an odor when the steam which arises from it carries away the odor of the coke.

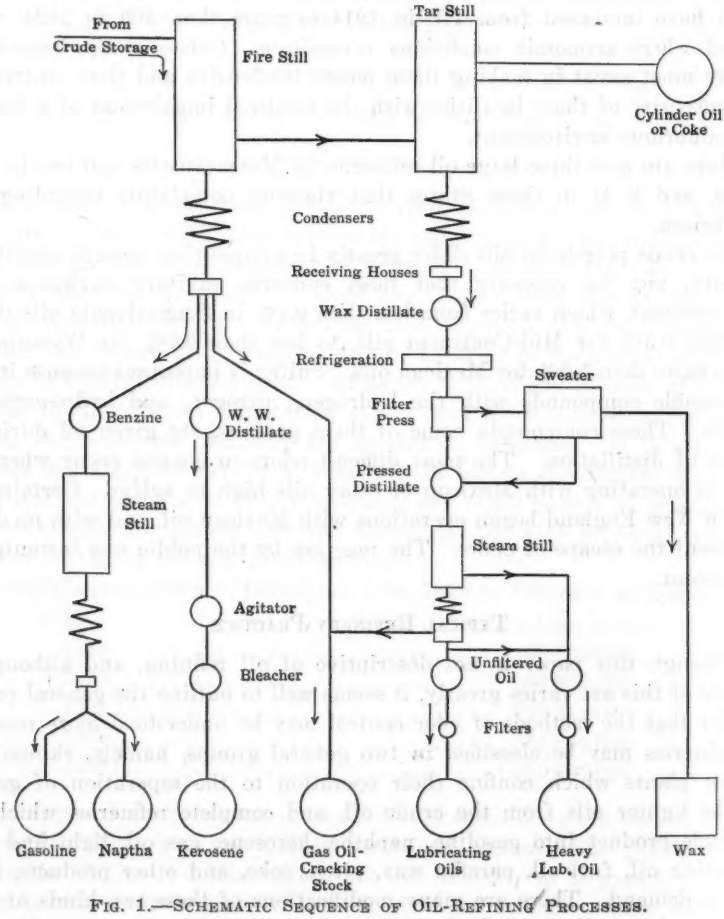
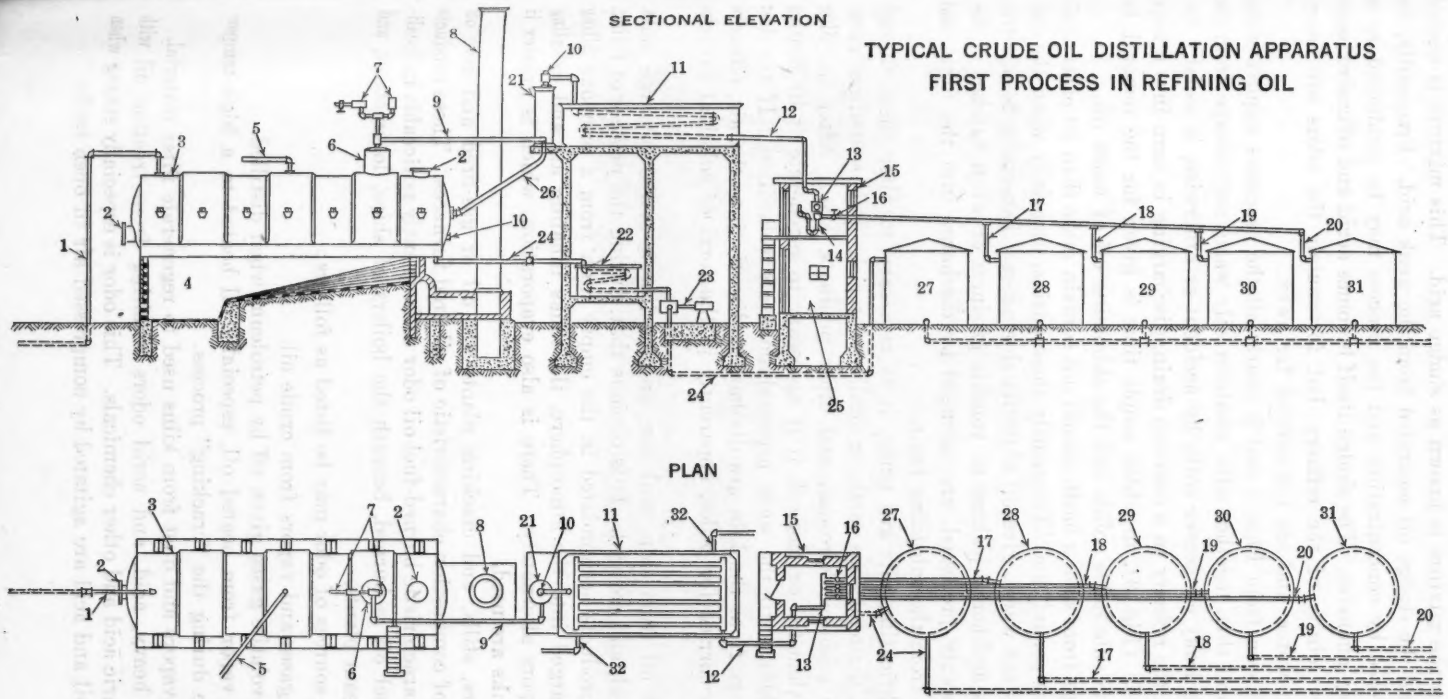


FIG. 1.—SCHEMATIC SEQUENCE OF OIL-REFINING PROCESSES.

During ordinary distillation, carbon accumulates on the shell of the still and the scale thus formed has to be removed by hand, at frequent intervals. The cleaning of stills, or tubes, is particularly frequent with the cracking process, in which high temperatures and pressures favor the deposition of carbon and make delays in cleaning dangerous.

Fuming sulfuric acid and lead oxide are used to treat gasoline and other lighter products to improve their odor. This is especially necessary if the crude oils contain sulfur and saturated hydro-carbons. This operation is usually conducted in tanks, operating either on the batch or the continuous system. The sulfuric acid carbonizes some of the asphaltic bodies and unsaturated hydro-carbons which settle to the bottom of the tank with the sulfuric acid,



1. Crude Oil Charging Line
2. Manholes
3. Crude Still
4. Firebox
5. Steam Line
6. Dome
7. Pressure and Vacuum Valves
8. Stack
9. Vapor Line
10. Thermometers
11. Condenser Box
12. Condensate Line
13. Lookbox
14. Water Leg
15. Receiving House
16. Manifold
17. Lubricating Distillate Lines
18. Gas Oil Distillate Lines
19. Kerosene Distillate Lines
20. Gasoline Distillate Lines
21. Dephlegmator
22. Tar Cooler
23. Tar Pump
24. Tar Lines
25. Instrument Room
26. Runback
27. Tar Storage
28. Lubricating Oil Distillate
29. Gas Oil Distillate
30. Kerosene Distillate
31. Gasolene Distillate
32. Water Lines for Condenser

FIG. 2.

in which form the mixture is known as sludge acid. This mixture is washed with water and the sludge oil separated from the weak acid. Frequently, the acid is recovered by concentration and the process may be conducted so as to be extremely offensive. The sludge itself becomes acrid and offensive, especially in the vicinity of the refinery, but fortunately the odors are heavy, are soluble in water, and are not carried far away.

As will be seen from Figs. 1 and 2, nearly all the processes require water for cooling, and this, together with whatever oily waste may escape from the plant through leaky condenser coils, by accident or otherwise, is usually discharged from the refinery in a common drain, discharging in turn into a large subsiding basin (Fig. 3), in which ample time is given for the removal, by gravity, of the subsidable solids and the skimming off of waste oil.

The effluent from such a basin should not contain more than 20 parts of oil (ether soluble) per million. Frequently these basins, especially when the condenser waters are warm, give off objectionable odors. Especially is this true when there is accidental leakage of volatile products or when batches of distillate, improperly processed, are salvaged by discharge into the drain and by skimming from the subsiding basin.

Where lubricating oils are made, it is necessary to filter them through fuller's earth, diatomaceous earth, or similar material. It is sometimes necessary to filter gasoline, kerosene, and other products, also. After the filter material is exhausted or clogged, it is necessary to regenerate it by heating in a rotary kiln until the waxy accumulations are volatilized. If the dust and oily vapors from the kiln are discharged directly into the air, offensive odors may be carried for miles, apparently in the form of colloidal particles of oily dust.

The crude oil from ship, tank car, or pipe line is stored in large tanks, usually of steel, and covered. It is obvious that, during the process of filling, the gaseous products accumulated in the empty tank from a previous filling will be discharged into the atmosphere, the tanks inhaling air and exhaling petroleum vapors alternately. There is also evaporation, which is greater if uncovered tanks are used.

The boilers, stills, and cracking plants are oil or gas-fired and give off the products of combustion characteristic of oil-fired furnaces. These products possess the characteristic burned-fuel-oil odor so frequently noticeable in localities where fuel oil is burned, beneath the boilers of ships, locomotives, and stationary steam plants.

The main sources of odor may be listed as follows:

(1) The gases and vapors from crude oil.
(2) The volatile gases given off by petroleum when distilled.
(3) The vapor from heated oil, especially oil heated to a high temperature during the "cracking" process.
(4) The vapors and dust from kilns used to regenerate filter material.
(5) The heavy, acid, and acrid odors resulting from treating oil with sulfuric acid and other chemicals. This odor is especially strong when the oil and acid are agitated by compressed air in open tanks.

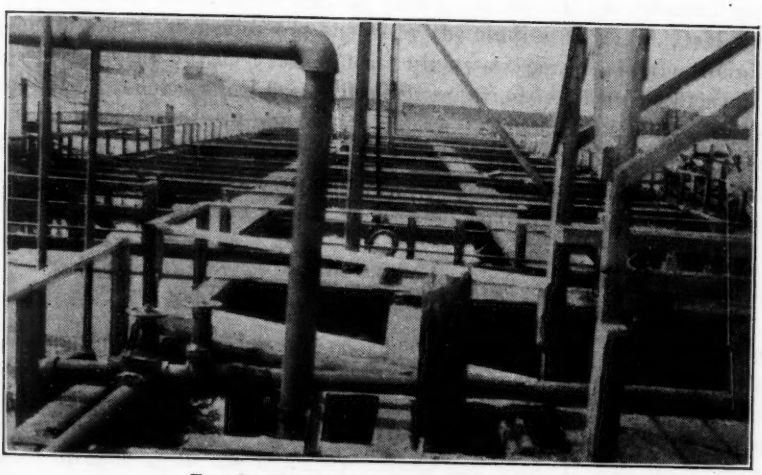


FIG. 3.—SKIMMING OR SEPARATOR TANK.

(6) The emanations from the surfaces of subsiding or separating basins and from the surface of water in gas-holders.
(7) The vapors given off from hot coke or pitch freshly drawn from the still.
(8) The vapors given off from stills when opened and steamed after a distillation has been completed.
(9) The stack gases from oil-fired furnaces; this is the most prevalent odor.

The substances included in these odors are petroleum and asphaltic hydrocarbons, hydrogen sulfide, carbon bisulfide, sulfur dioxide, sulfur trioxide, pyridin vapors, the oxides of carbon, and various volatile compounds of sulfur or sulfur and nitrogen, of which the offensively smelling mercaptan is an example.

That some of these odors may be present in the air in sufficient concentrations to affect the health was shown by the studies of Mr. S. DeM. Gage,* who reported that during 1921 at least ninety-six persons in the vicinity of Rhode Island refineries had been more or less seriously affected by them. The symptoms most frequently noted were nausea, headache, vomiting, sore throat, and insomnia, and it was the opinion of the majority of physicians consulted that asthma, respiratory diseases, and nervous diseases were unfavorably affected by petroleum and sulfur odors and also by the sulfur dioxide and trioxide gases.

Nature of the Odoriferous Matters

The matters which produce the odor may be divided into two classes, namely true gases and vapors. The true gases diffuse rapidly and the intensity of the odor roughly varies inversely as the square of the distance. Not so the odor produced by vapors which, in the form of minute particles, "odorphores", impinge directly upon the olfactory organs and seem to lose their intensity very slowly with distance, within the sector where their presence may be observed. The distances to which they may be observed seem to depend more upon the humidity and the character of the air currents which carry them than upon any other factors.

For example, the writer has observed the acrid odor from sludge acid when it was so strong that it was impossible to remain a whole minute in its presence. Yet this odor could not be observed ½ mile to the leeward of its point of origin. On the other hand, the sulfur compounds in the vapors given off from Mexican oil were at least one-fourth as intense 2 miles away as they were in the refinery yard where they were produced.

The odors from the kilns in which material used to filter the various distillates is ignited to regenerate it, also have the power of traveling great distances. This is probably due to the fact that the dust particles from the kiln become coated with a film of oil, and in this state become dispersed in the air, much as pollen and other dust particles are dispersed.

* Report of Rhode Island State Board of Health on the Cause, Prevalence and Effect of Offensive Odors in Providence, Cranston, East Providence and Warwick during 1921.

Character and Intensity of Odors

It is a fact of physiology that the nose detects two classes of odors: First, the true odors which are observed by organs located in the upper nasal passages behind the superior turbinated bones; and, second, the irritants which are observed by a separate set of nerve endings in the anterior part of the nose. For example, perfumes are perceived by one set of nerves, whereas irritants like ammonia and pyridin, affect the other set. Certain substances like tobacco smoke, for example, are both odoriferous and irritating, and the odors given off by oil refineries are in either or both of the two classes.

Oily vapors, for example, volatilized vaseline, possess true odors which are not irritating, whereas sulfur trioxide is sometimes recognized by its irritating effect, before being detected by the olfactory organs. Certain volatile hydro-carbons are also highly odoriferous, but are not irritating unless present in high concentrations.

It is a peculiarity of the olfactory organ, by which the true odors are detected, that it tires rapidly and that ordinarily sniffing is required to carry odor to the portion of the lining membrane of the nose where in a small area (25 mm. square on each side) the special organs are located.

Names of Odors.—Various observers have given names to the various odors, and sometimes various names to the same odor observed about oil refineries. For convenience, the following adjectives have been used in the writer's practice:

Adjective.	Description of Odor.
Sweetish	The odor of gasoline and refined petroleum products.
Turnipy	The odor of well-diluted petroleum gases containing sulfur and nitrogen.
Onion or garlicy	The same odor in higher concentration.
Sulfide	The rotten-egg-like odor of hydrogen sulfide gas.
Sulfur trioxide	The characteristic odor of fuming sulfuric acid. In considerable dilutions this is detected by its effect upon the mucous membrane and without the accompaniment of any true odor.
Oily	The odor of volatilized petroleum distillate as from a fuel oil tank.
Burned oily	The characteristic odor from oil-fired furnaces.
Burned rubber	The burned oily odor in higher concentration.

Any of these odors may exist singly, or in combination, and the combinations may possess odors and irritants which are difficult to analyze.

Intensity of Odors.—The intensity of odor may be graded on a scale of 5, as follows:

Number.	Corresponding Adjective.
1	Very faint
2	Faint
3	Distinct
4	Decided
5	Strong

Detection of Odors.—Two methods of detection are usually practiced, namely, smelling and chemical analysis.

Smelling.—The nerve ends in the nose not only are delicate qualitative instruments, but when the results of their trained use are classified and the adjectives pertaining to quality are given numerical values, they do more reliable work than any mechanical instrument; because, after all, the reaction of a complaining public depends upon nasal observations and not the qualitative results of chemical air analyses, which are of little practical meaning to them. Furthermore, an observer becomes expert with training and can detect and describe odors which baffle a lay observer. His observations are of especial value when a differentiation of sources of odor is required.

Gas Analyses.—Chemical gas analysis methods are more effective for the detection of the irritating sulfur gases, it being possible to measure concentrations which are about one-tenth of those which may be detected by the nose. For example, hydrogen sulfide may be smelled in concentrations of 100 parts in 1 000 000 000 parts of air, whereas the same gas may be detected in concentrations of 15 parts in 1 000 000 000 parts of air, by chemical analysis, using 100-liter portions for each determination.

The Nasal Method.—The first requisite for this method is an observer of keen perceptions, one who is quick to notice any change in atmospheric conditions and who can make judicial records of his observation.

The automobile is a great convenience for making observations, but care should be taken to select a machine which emits the minimum of oily odors, and when making observations, the observer should step out of the automobile so as to avoid any error due to observing the products in the exhaust of the motor in place of those present in the air at the point of observation.

While making record of nasal observations, together with those of wind and weather, a sheet, Table 1, has been used by the writer's firm. It will be noted that there are spaces for recording the velocities and the direction of the wind at various times of observation, the weather, and the time, place, kind, intensity, and probable source of any odors observed. Space is also provided for smoke observations for the reason that the burned oily odor from stacks connected with oil-fired furnaces, is more or less proportional to the density of the smoke emitted from them.

At Fall River, Mass., eight stacks were observed. Some of these were within the refinery yard, and others were connected with various mills within two miles of the refinery. Ringelmann's chart was used to record the percentage of black smoke in the emanations from the various stacks. The relative humidity was observed at one station only.

Having made the observations, the next step is to express them in diagrammatic form. For this purpose, reproductions of a map of the vicinity of the refinery about which observations are made, are useful, and Figs. 4 and 5 show the map-diagrams which were used at Fall River and at East Braintree, Mass., and vicinity, respectively.

The Fall River map-diagram, which records the observations for 24 hours ending at 7 A. M. on July 25, 1922, shows a summary of the weather, wind,

TABLE 1.—Report of Odor Observations.

(For 4 Hours Ending at 7 A. M., July 25, 1922, at Fall River, Mass., New England Oil Refining Company.)

Wind.				Weather.
Velocity.	Direction.	From.	To.	
Light.....	N—NNE	3	4	Cloudy
"	NNE—N—NE	4	5	"
"	NNE—NE	5	6	Partly cloudy
"	"	6	7	"

Odors Observed.

Time.	Place.	Kind.	Intensity.	Source.
3:45	Lincoln Ave. between Rock and Belmont Sts.....	Onion—sweetish.	Faint.....	N. E. O. R. Co.
4:00	President Ave. between N. Main and railroad.....	"	Very faint.....	"
4:15—4:30	Cedar to Pine on N. Main—N. Main to Dartmouth on Pine.	Burnt oily.....	Faint to distinct...	Electric Light Plant
6:00	Brightman between railroad and St. Mary St.....	Onion—sweetish.	Very faint.....	N. E. O. R. Co.
6:30	Bradford Ave., Dimon to Day Sts.....	Burnt oily.....	Faint traces only..	American Print Wks.

Smoke Observations—Densities according to Ringelmann's Chart.—Per Cent. Black.

Time.	S 1	%	S 1*a*	%	S 1*b*	%	S 2	%	S 1/10	%	S 1 1/2 0	%	S 2 6/10	%	C k S	%	S	%
5:45		20		40		10		10		10		10		0		10		

Remarks

Observer.

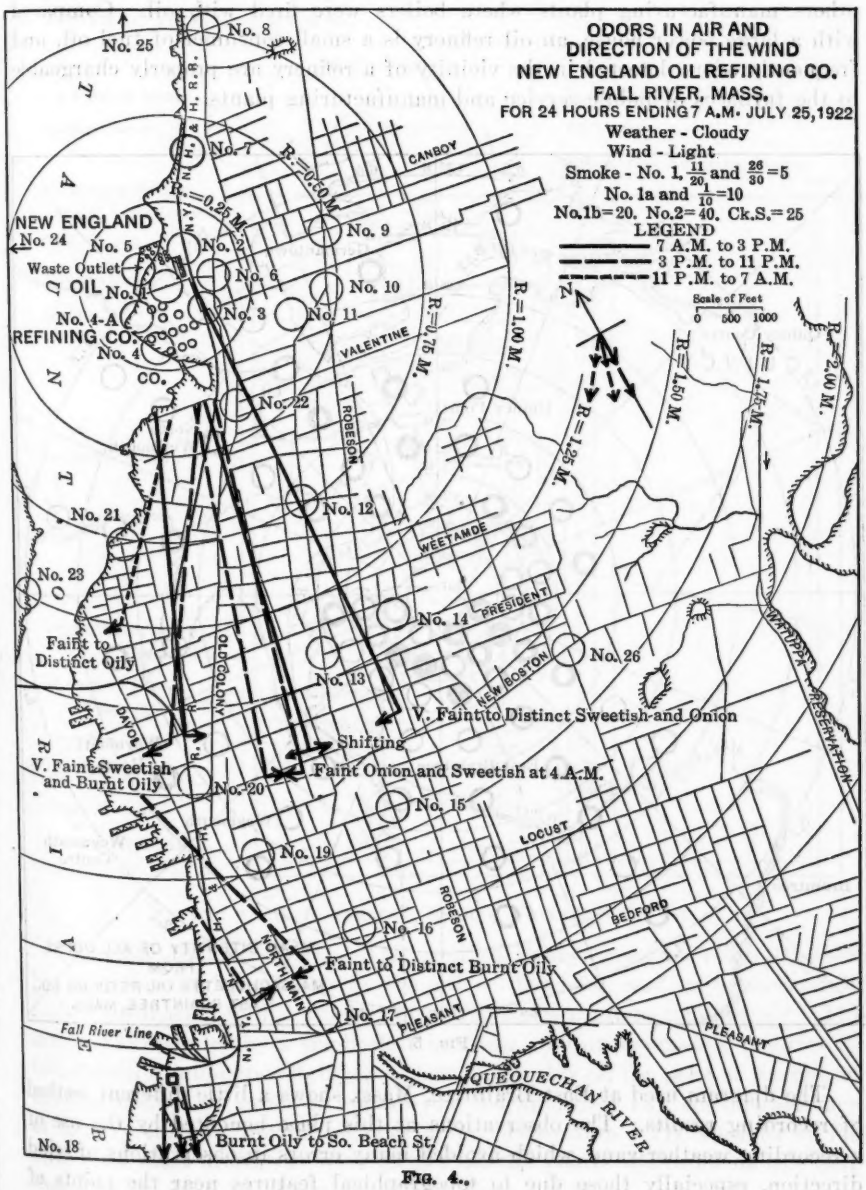

ODORS IN AIR AND
DIRECTION OF THE WIND
NEW ENGLAND OIL REFINING CO.
FALL RIVER, MASS.
FOR 24 HOURS ENDING 7 A.M. JULY 25, 1922
Weather - Cloudy
Wind - Light
Smoke - No. 1, 11/20 and 26/30 = 5
No. 1a and 1/10 = 10
No. 1b = 20. No. 2 = 40. Ck. S. = 25
LEGEND
7 A.M. to 3 P.M.
3 P.M. to 11 P.M.
11 P.M. to 7 A.M.
Scale of Feet
0 500 1000
NEW ENGLAND OIL REFINING CO.
Waste Outlet
No. 25
No. 8
No. 7
No. 24
No. 5
No. 2
No. 1
No. 6
No. 9
No. 10
No. 11
No. 3
No. 4-A
No. 4
No. 22
No. 12
No. 21
No. 23
No. 14
No. 26
No. 13
No. 20
No. 15
No. 19
No. 16
No. 17
No. 18
R. = 0.25 M.
R. = 0.50 M.
R. = 0.75 M.
R. = 1.00 M.
R. = 1.25 M.
R. = 1.50 M.
R. = 1.75 M.
R. = 2.00 M.
CANBOY
VALENTINE
ROBESON
WEETAMOE
PRESIDENT
NEW BOSTON
OLD COLONY
DANOL
LOCUST
BEDFORD
PLEASANT
NORTH MAIN
Fall River Line
QUEQUECHAN RIVER
MARIPPA RESERVATION
Faint to Distinct Oily
V. Faint to Distinct Sweetish and Onion
Shifting
Faint Onion and Sweetish at 4 A.M.
V. Faint Sweetish and Burnt Oily
Faint to Distinct Burnt Oily
Burnt Oily to So. Beach St.

FIG. 4.

smoke observations, the intensities and kinds of odors, and the areas within which the odors were observed. It will also be noted that odors were observed as coming from three sources, one of which was the oil refinery and the others manufacturing plants where boilers were fired with oil. Compared with a large power house, an oil refinery is a small consumer of fuel oil, and frequently odors detected in the vicinity of a refinery are properly chargeable to the furnaces of public service and manufacturing plants.

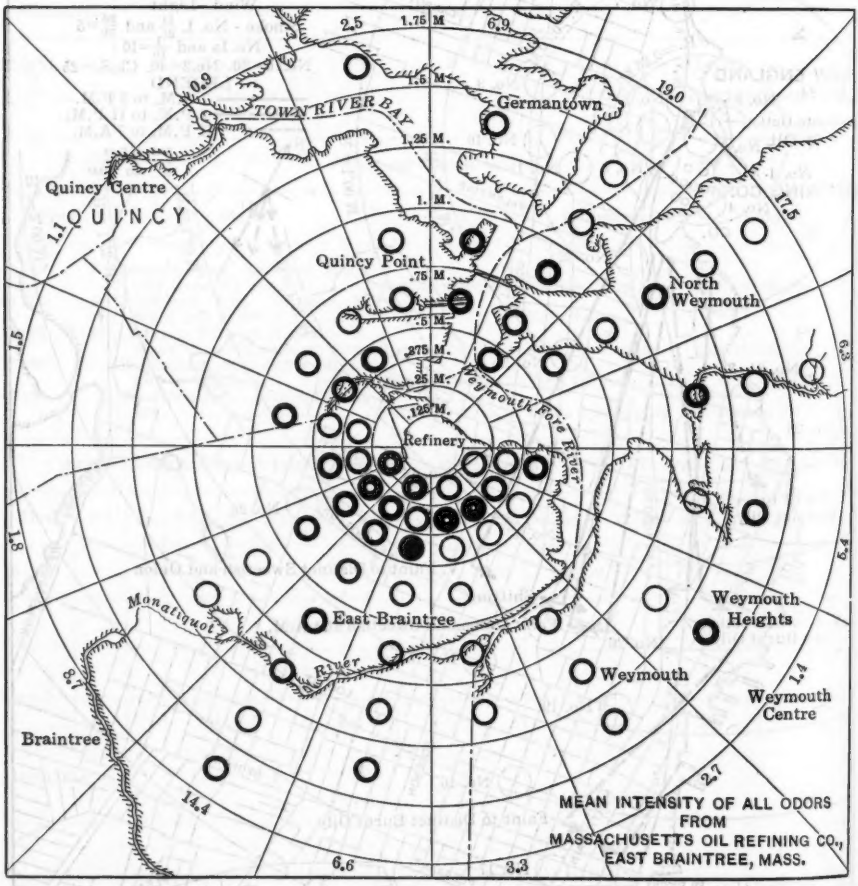


FIG. 5.

The diagram used at East Braintree, Mass., shows a little different method of recording results. The observations at this place benefited by the use of a recording weather-vane, which avoided many errors in observations of wind direction, especially those due to topographical features near the points of observation.

On the diagram referred to (Fig. 5), various data were recorded by the use of symbols, and the illustration is one showing the mean intensity of all odors

in each sector of 22.5° and the relative mean intensities of these odors in the section of each annulus lying within the sector, the mean intensities in each sector being expressed by figures, and those in each section of an annulus by circles of varying heaviness.

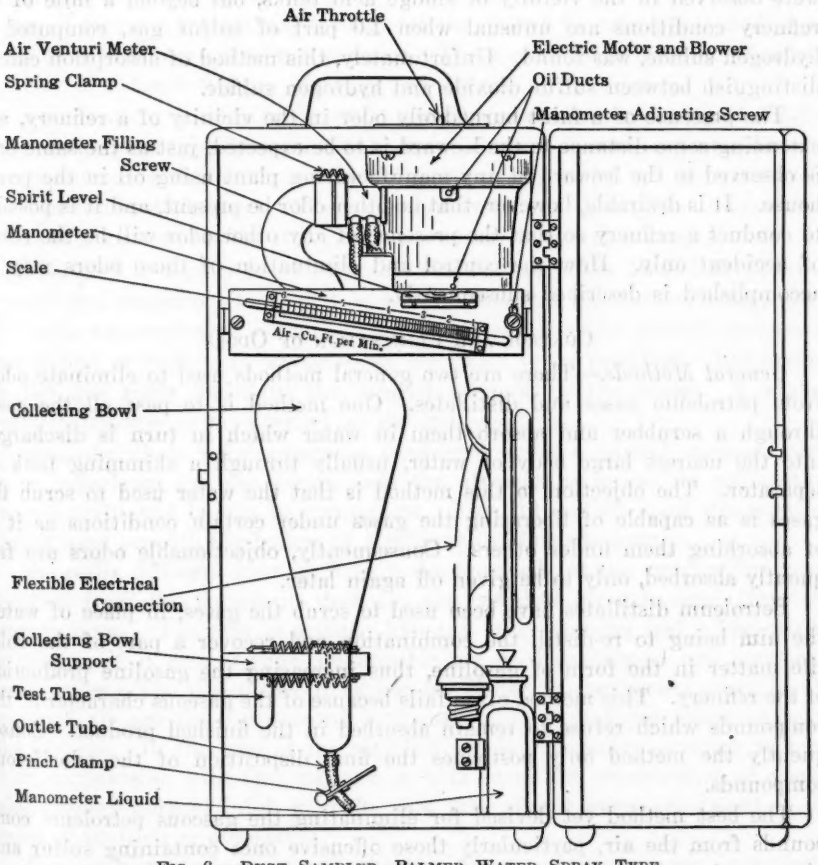


FIG. 6.—DUST SAMPLER, PALMER WATER SPRAY TYPE.

Chemical Analysis of Air.—The modified Palmer machine (Fig. 6), which has been described previously by the writer* has been used quite successfully for the estimation of the amount of sulfur gases contained in the air. This machine is operated by a small electric motor, and unfortunately requires the installation of numerous lighting sockets, preferably on the poles of the electric lighting system, in order to operate the machine over any considerable area of country surrounding the refinery under observation. The stations at Fall River and East Braintree were located at the points indicated on the map-diagrams (Figs. 4 and 5) by numbered rings.

By means of the Palmer machine, 100 liters of air could be aspirated through nebulized caustic-soda solution and the sulfur gases absorbed determined by

* *Transactions*, Am. Soc. C. E., Vol. LXXXV (1922), p. 420.

the usual chemical method. This method is similar to the one used by the copper companies in the West for the detection of sulfur dioxide in the gases emitted from smelters. Usually the concentrations of gas found in the air were very minute, although concentrations as high as 50 parts per 1 000 000 were observed in the vicinity of sludge acid tanks, but beyond a mile of the refinery conditions are unusual when 1.0 part of sulfur gas, computed as hydrogen sulfide, was found. Unfortunately, this method of absorption cannot distinguish between sulfur dioxide and hydrogen sulfide.

The presence of a faint burned-oily odor in the vicinity of a refinery, and extending some distance to the leeward is to be expected, just as the same odor is observed to the leeward of any manufacturing plant using oil in the power house. It is desirable, however, that no other odor be present, and it is possible to conduct a refinery so that the presence of any other odor will be the result of accident only. How the control and elimination of these odors may be accomplished is described subsequently.

Control and Elimination of Odors

General Methods.—There are two general methods used to eliminate odors from petroleum gases and distillates. One method is to pass all the gases through a scrubber and absorb them in water which in turn is discharged into the nearest large body of water, usually through a skimming tank or separator. The objection to this method is that the water used to scrub the gases is as capable of liberating the gases under certain conditions as it is of absorbing them under others. Consequently, objectionable odors are frequently absorbed, only to be given off again later.

Petroleum distillates have been used to scrub the gases, in place of water, the aim being to re-distill the combination and recover a part of the volatile matter in the form of gasoline, thus increasing the gasoline production of the refinery. This method often fails because of the gaseous character of the compounds which refuse to remain absorbed in the finished product. Consequently the method only postpones the final disposition of the odoriferous compounds.

The best method yet devised for eliminating the gaseous petroleum compounds from the air, particularly those offensive ones containing sulfur and nitrogen, is to collect them by means of a vacuum system, and to burn them beneath a still or boiler. This method is not only practicable, but effects a considerable economy of fuel.

The danger in carrying out this process is one of forming explosive combinations of air and petroleum vapors. This can be guarded against, however, by placing Monel metal screens, Figs. 7, 8, and 9, at various convenient points in the collecting piping. These screens act upon the safety-lamp principle and prevent backfiring of the vapors.

Another requisite of the process is to provide for variations in the rate of gas emanation, for it is obvious that when a still is freshly charged, the rate of gas evolution from it is greater than later in the distillation process. On the other hand, the rate of burning gas beneath boilers is more nearly constant. Consequently, it is necessary to store the gas during the peaks in production

for use during periods of low production. For this purpose, gas-holders similar to those used in illuminating gas-works are used. The gas-holders are connected with the gas mains, and maintain a practically constant pressure at the burners beneath the stills, furnaces, or boilers. A partial vacuum of a few inches of water is maintained throughout the system by exhausters similar to those used in illuminating gas practice. These exhausters must be of ample capacity to exhaust the gas regardless of the rate of production.

It is usual to provide two vacuum systems, one connected with the stills, from which gases rich in combustible material are collected, and another system connected with the tanks, the collections from which are comparatively weak in combustible gases. The collection system for the tanks is somewhat different from that for the stills in that some air is collected at all times.

Each tank is usually provided with a seal or trap (Figs. 10 and 11), having a water seal equivalent to a depth of water of about 1 in. Consequently, when the tanks are connected with the vacuum system, a slight partial vacuum is maintained at each tank where odors are likely to be produced. Exhausters on the gas main maintain the desired vacuum in the tanks. A higher negative pressure is maintained on the still gas lines.

With the whole refining process conducted under a partial vacuum, little or no petroleum gas can escape into the atmosphere unless its combustion beneath stills and boilers be incomplete. Figs. 12 and 13 show the types of burner used beneath the boilers of a refinery in Massachusetts.

Naturally different burners have to be provided for the combustible gases distilled from the petroleum than for the enriched air exhausted from the storage tanks. The first is utilized like any other gaseous fuel. The second is used as if it were a semi-inflammable air used to support and accelerate combustion. The difficulties of caring for either the petroleum gases or the enriched air are those connected with maintaining a proper temperature in the furnace. In the case of the enriched air, it is usually necessary to burn it in conjunction with fuel oil, and in both cases the construction of a suitable checker-work of brick to make sure that all the gases are raised to the point of ignition is necessary.

Occasionally stack gases will show evidences of having been imperfectly consumed in the furnace, and where oils high in sulfur are refined, may contain the objectionable nitrogen-sulfur compounds. The usual remedy in such cases is to raise the temperature of the furnace, although experiments made under the direction of the writer have shown that the introduction of a small amount of chlorine gas into the stack gases will so change their character that they will become unobjectionable. This process is the one so successfully applied by Professors Henderson and Haggard to garbage plants to overcome the disagreeable odors emanating therefrom.

Odors from Sludge Acid.—The disagreeable acrid odor given off by sludge acid is difficult to control. In some plants, the material is removed and covered with earth. This requires a large area, usually not available in connection with a refinery. The sludge is washed in water to recover the acid and the weak acid is concentrated by distillation in a closed system provided with

devices for maintaining a partial vacuum by a method similar to that used in the petroleum stills. By the use of this apparatus, in which the weak acid may be agitated with superheated air, or heated in a retort, the emanation of disagreeable odors may be eliminated. Furthermore, the recovered acid may be re-used for refining oil.

Because the actual volumes of sludge acid discharged from a large plant are small, it is frequently advisable to ship acid from several refineries to a central plant for the reclamation of the acid. This plant may be located where there is the minimal danger of nuisance.

The Discharge of Oil into Watercourses.—It is probable that the befouling of shore waters and bathing beaches by discharges of oil has given rise to as serious complaints as the discharge of odor into the air. It is beyond the province of this paper to discuss this nuisance beyond stating that the discharges which come or might come from an oil refinery are readily controlled by skimming off separating tanks, the effluent from which should not contain more than 20 parts per 1 000 000 of ether soluble oil, the discharge of which in so great dilution into any considerable body of water may be made with impunity. Usually the befouling of shore waters and beaches is from shipping and sources other than oil refineries.

Although the principle of odor-control by operation *in vacuo* is simple, its carrying out is a matter requiring care and involving large expense for construction, maintenance, and inspection. It is not enough to have a single connection with each still or condenser, but each high point must be connected with the general system through a separate pipe, each pipe provided with a shut-off valve for use in case of accident. (Figs. 14, 15, and 16.) Furthermore, the workmanship must be of the best to avoid gas leakage. In addition, frequent traps (Fig. 17) for the interception of liquids are necessary, and also devices for separating the intercepted petroleum products without discharge into the air. Fig. 15 shows the extensive piping required to exhaust the gases from a battery of stills.

Not only must the stills be vented, but the use of open tanks for chemical treatment of distillates must be avoided. Fig. 18 shows the method of covering tanks and exhausting the gases arising from a group of agitators.

The control of the odors emanating from the skimming basin is seldom attempted. Fortunately these odors are not usually strong except when accidental discharges of the lighter distillate happen to occur. Usually the odors are imperceptible beyond the refinery yard. The method of guarding against their spreading is to construct a high fence about the basin to minimize the movement of air currents.

Naturally the water in a gas-holder absorbs and gives off disagreeable odors. These may be largely controlled by renewing the water in the gas-holder and by preventing the circulation of the exposed surface water as much as possible. In some cases the addition of chemical absorbents has been practiced, but not generally.

Summary

Briefly, it may be stated that unless controlled, the odors emanating from an oil refinery may create a nuisance. These odors are due to various vapors

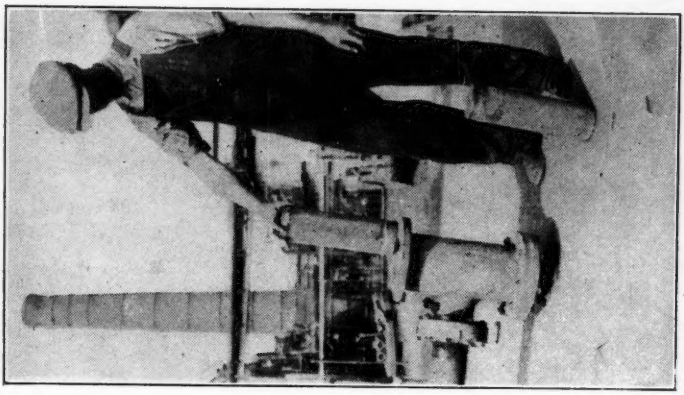


FIG. 8.—SAFETY SCREEN REMOVED FOR INSPECTION AND CLEANING.

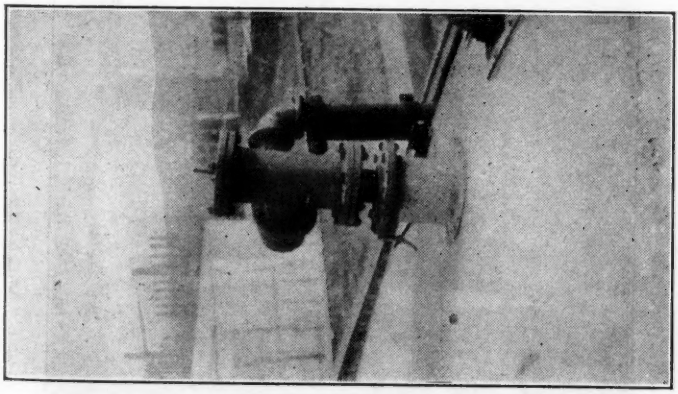


FIG. 7.—TEE CONTAINING SAFETY SCREEN.

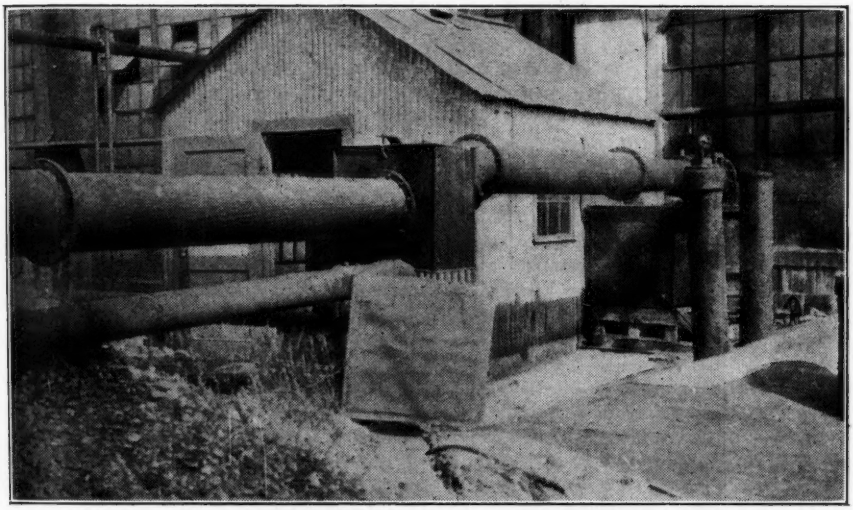


FIG. 9.—SAFETY SCREEN BOX AND SCREEN IN MAIN EXHAUST LINE FROM TANKS ALSO CHAMBER FOR INTERCEPTING LIQUID.

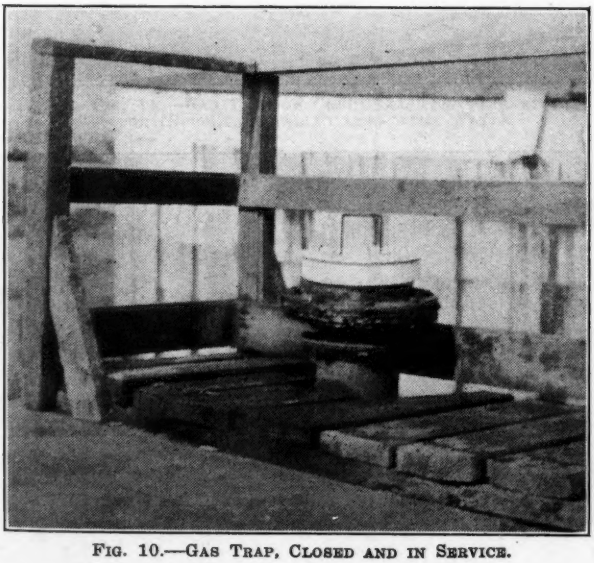


FIG. 10.—GAS TRAP, CLOSED AND IN SERVICE.

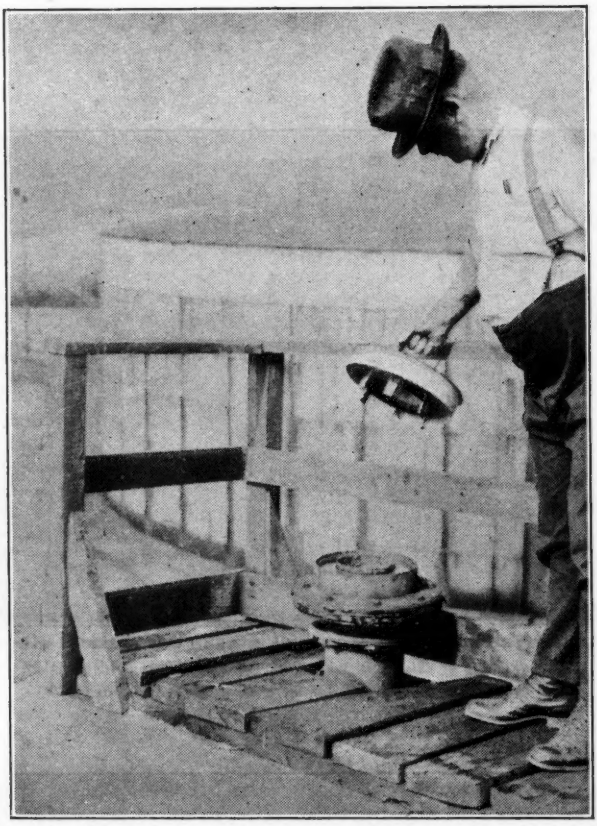


FIG. 11.—GAS TRAP ON CRUDE OIL TANK OPENED FOR INSPECTION AND FILLING WITH WATER.

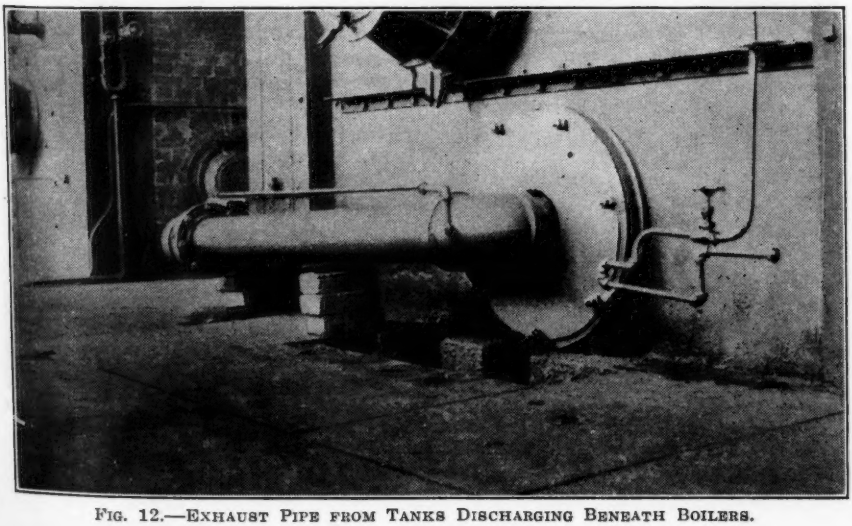


FIG. 12.—EXHAUST PIPE FROM TANKS DISCHARGING BENEATH BOILERS.

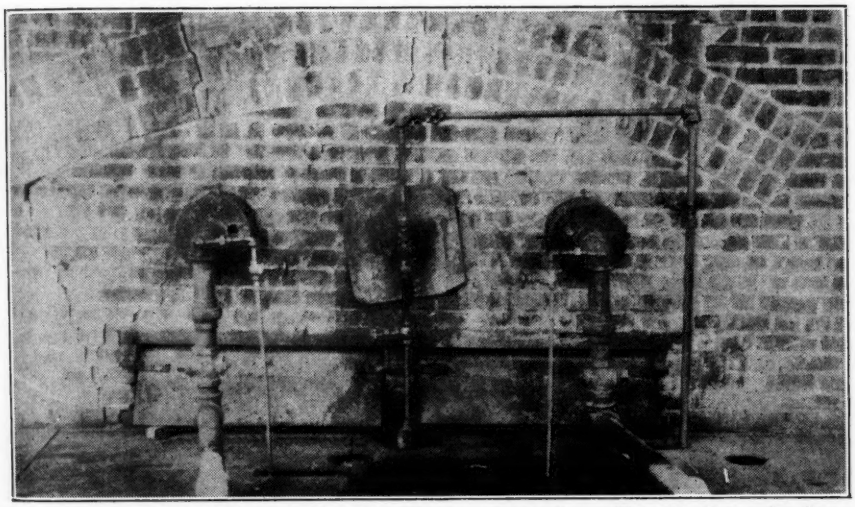


FIG. 13.—TWO GAS BURNERS AND ONE OIL BURNER (CENTER) FOR HEATING CRUDE OIL STILL.

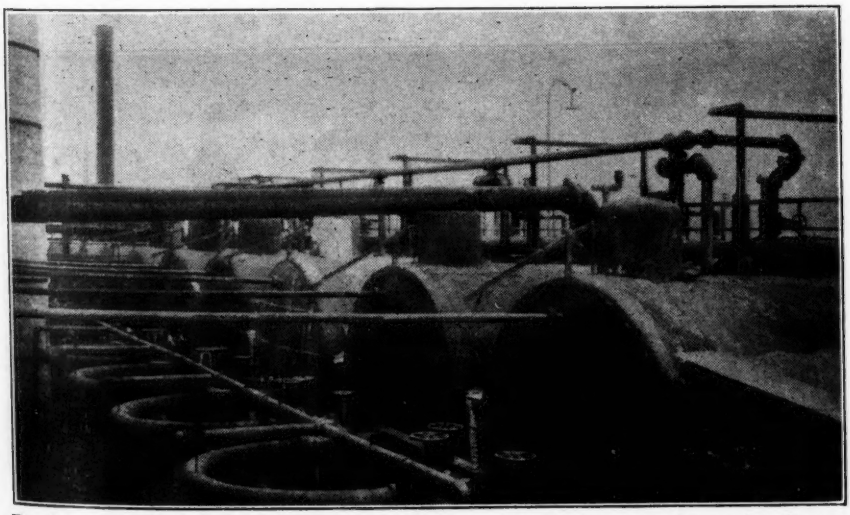
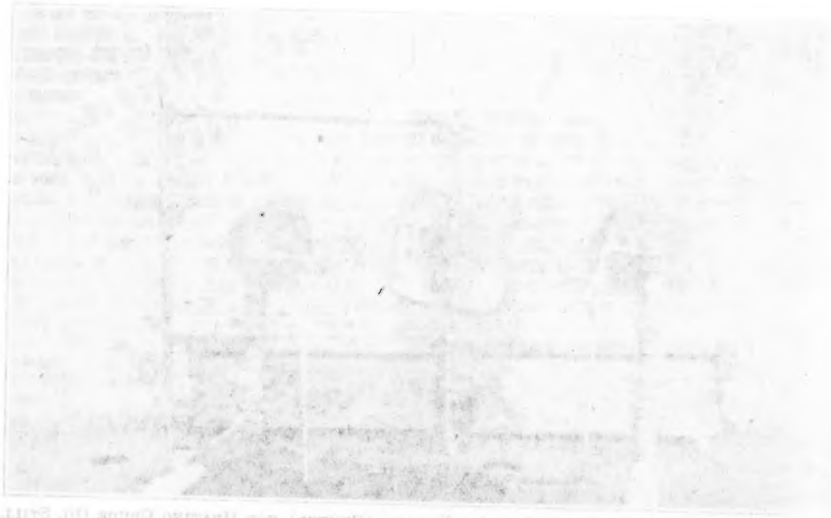
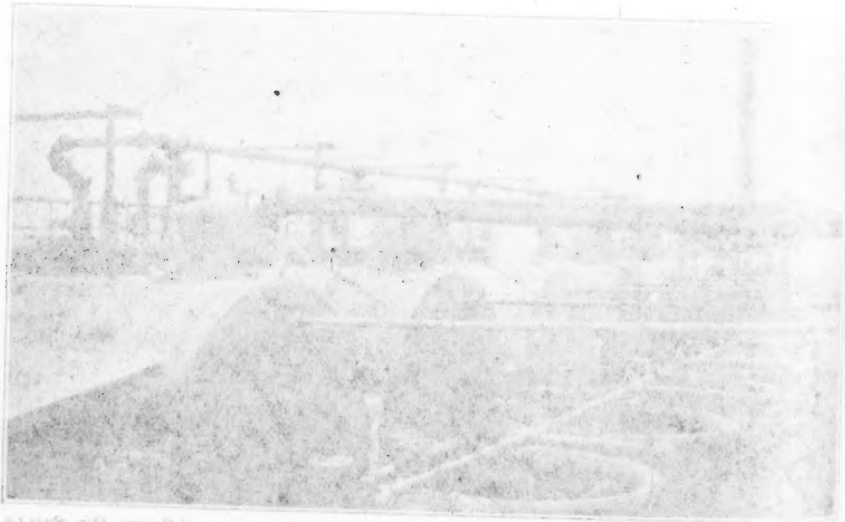


FIG. 14.—VACUUM AND OTHER PIPING IN THE REAR OF A BATTERY OF CRUDE OIL STILLS.





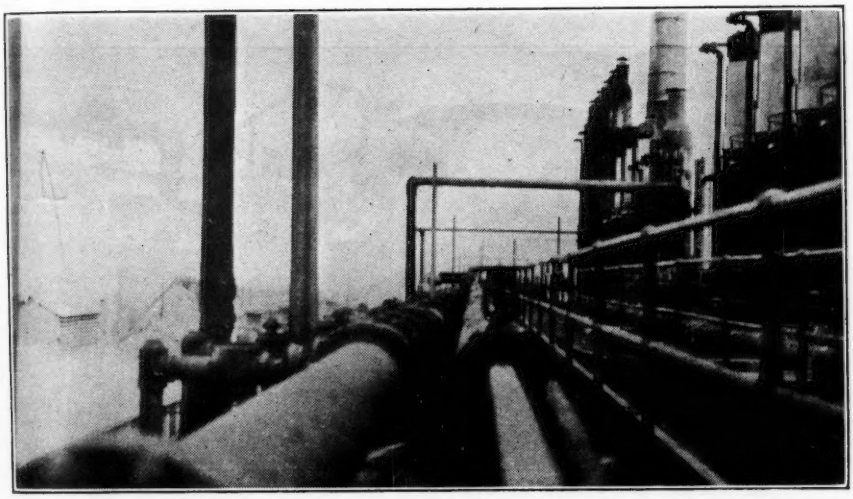


FIG. 15.—VACUUM AND WATER PIPING IN THE REAR OF DEPHLEGMATORS AND ABOVE CONDENSERS.

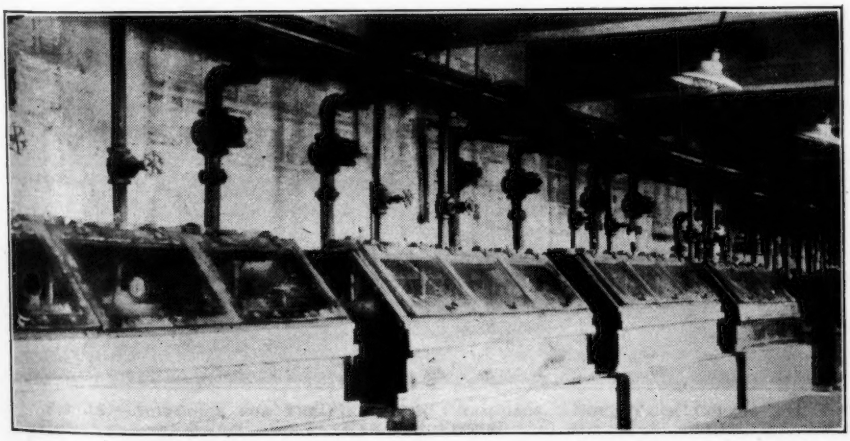
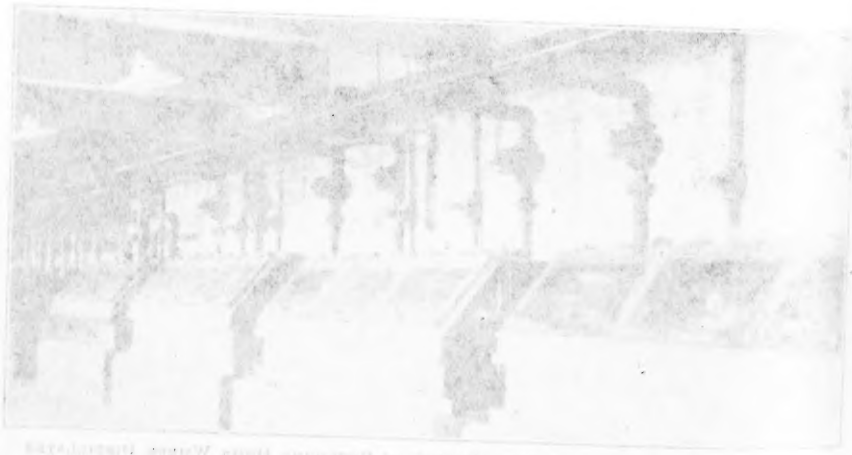


FIG. 16.—VACUUM PIPING AND "LOOK BOXES" IN RECEIVING HOME WHERE DISTILLATES ARE DISCHARGED.



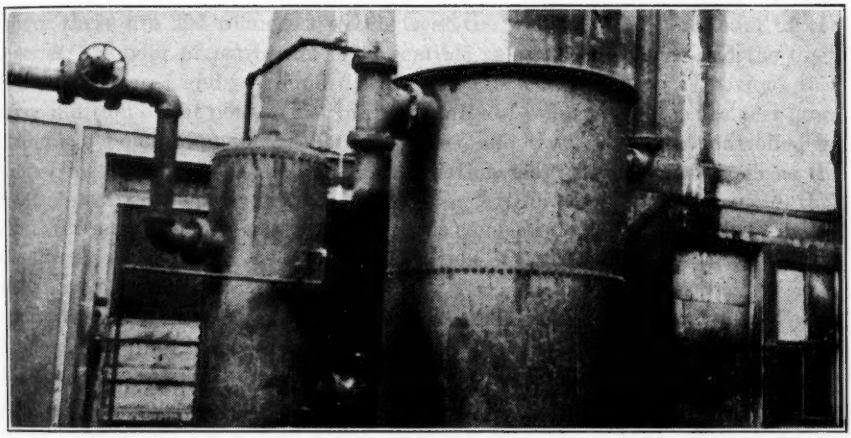


FIG. 17.—TRAP IN VACUUM GAS LINE BETWEEN STILLS AND EXHAUSTER.

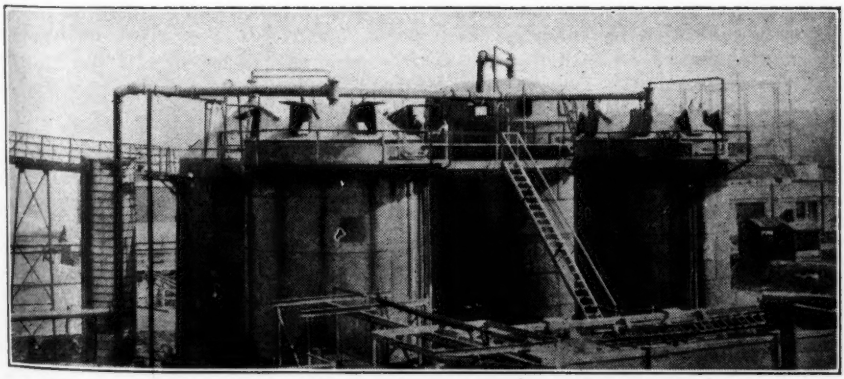


FIG. 18.—AGITATORS FOR TREATING WITH CHEMICALS. NOTE TANK COVERS AND EXHAUST PIPING.

and gases emitted during the process of refining, and the best method of controlling and eliminating them is to collect them at all possible points of discharge by means of vacuum-collecting systems, to store the gases so collected, and to discharge them into properly designed furnaces in which, with or without the aid of other fuel, they will be completely consumed.

Travelers have reported that in the "Black City" near Baku, in Russia, where there are 200 refineries which treat the whole of the petroleum of the district, the odor of petroleum is perceptible at a great distance and the town is always covered and surrounded with dense, black smoke. It is obvious that this condition ought not to exist in the vicinity of refineries which are near large centers of population in the United States, and they should be controlled by proper methods, even though their installation may cost 10% as much as the total cost of the refinery construction. It is fortunate, on the other hand, that the investment in a gas-collecting system is compensated in great part at least by the large saving in fuel due to the utilization of combustible gases for heating stills and boilers.

Air cleaning, like river and harbor cleaning, is a problem connected with the concentration of population and has become an art which all communities that wish to maintain a high degree of civilization, with health and happiness for all, must practice.

In conclusion, the writer wishes to thank the officers of the New England Oil Refining Company, and particularly Mr. D. T. Schulz, General Superintendent, for permission to publish certain information, and assistance in preparing the illustrations in this paper.

PROGRESS REPORT OF THE SPECIAL COMMITTEE TO CODIFY PRESENT PRACTICE ON THE BEARING VALUE OF SOILS FOR FOUNDATIONS, ETC.*

To the Members of the American Society of Civil Engineers:

Your Special Committee investigating "the Physics of Soils in Relation to Engineering Structures" respectfully submits this interim report.

In October, 1924, the Committee had one general meeting and reported progress to the Board of Direction. At this meeting, by invitation, Dr. Carl C. Zon Caldenius, of Stockholm, Sweden, a member of the Royal Geo-Technical Commission of the State Railways of Sweden, investigating landslides and similar phenomena, explained the work of the Royal Commissions during the past few years and the results as embodied in their last report. The brief discussion that followed indicated the wide interest in the problems before the Committee.

The expenses of the Committee for 1924 have been about $60. The available funds were small and limited activities to the study of contemporaneous research. If the recent rapid advancement in knowledge of the physics of soils is maintained the early submission of a useful report may be expected.

For many years the soil has been regarded as a mass of crystalloid mineral matter, and sand has been used in experiments on the physical properties of the soil. In the earlier attempts at mathematical analysis the sand particles were supposed to be spherical and impenetrable, although this assumption was recognized as merely an approximation. As experimental results and deductions accumulated it became evident that there was a wide discrepancy between the properties anticipated and those actually found in natural soils. It therefore became necessary to re-examine the fundamental principles.

The demonstrations by the Dutch investigator, Van Bemmelen, as to the unsoundness of the old views is now accepted. Further investigations have shown that soil is essentially a colloid and that soil absorption is a manifestation of its colloidal properties.

The facts observed by Keen in the evaporation of water from soil are explained by regarding them as colloidal effects. He found that the relationships of water to soil differ considerably from its relationships to sand. The evaporation of water from sand, silt, etc., proved to be relatively simple and could be explained by the known laws of evaporation and diffusion; but the evaporation of water from soil could not—it was more complex. The difference was traced to the soil colloids and disappeared when the soil was ignited and

* Presented to the Annual Meeting, January 21, 1925. Previous Progress Reports of this Special Committee have been published in *Proceedings*, Am. Soc. C. E. (Papers and Discussions), February, 1915, p. 491; March, 1916, p. 343; August, 1917, p. 1171; August, 1920, p. 905; February, 1921, p. 9; March, 1922, p. 523; and October, 1923, p. 1732.

the colloidal properties were lost; the curve then became identical with that obtained for sand.

Other investigators have found that the quantity of water absorbed by dry soil from a moist atmosphere, the water-holding capacity, and the resistance to drainage, are doubtless influenced by soil colloids.

The study of soil colloids has been disregarded until recent years, but now its importance in soil physics is established beyond all doubt.

The researches presented in previous reports by the Committee have been brought up to date in Appendix I to this report, by an authoritative contribution on "Recent Investigations of Soil Colloids", by Philip L. Gile, Chief, Division of Chemical Investigations, through the courtesy of Professor Milton Whitney, Director, Bureau of Soils, United States Department of Agriculture.

In an earlier report (1922)* the Committee referred to its difficulties in considering the relative merits of methods for the determination of the quantity of colloidal matter in soils.

The measurement of the quantity of dye which soil can absorb has been elaborated by many investigators, but quantitative results have not been particularly successful. The chief objection to the method as a quantitative one lies in the fact that the absorption of the dye depends on the degree of dispersion as well as on the quantity of colloidal material, while from the quantitative point of view mica and certain other substances tend to absorb the dye.

According to Stremme and Aarnio, the most reliable method is that of Rodwald-Mitscherlich, which depends on the absorption of water vapor, that is, on the determination of the hygroscopicity.

For routine work, Mr. Gile has proposed a tentative method based on determining the quantity of water vapor absorbed. It would prove helpful to the Committee if members of the Society would report their experiences in the use of this method.

The only other method considered has been the dehydration and rehydration curve method of Van Bemmelen. This method has been used largely to discriminate between the various types of clays.

Different methods do not give altogether concordant results nor is it to be expected that they should; it is highly improbable that any sharp dividing line exists in the soil between the colloids and the non-colloids; intermediate substances are to be expected, showing colloidal properties only to a slight extent.

At present, many characteristics of soils are inexplicable, but a study of the physical properties of colloidal materials isolated from a number of different soils is now being made by the U. S. Bureau of Soils, and valuable results are expected.

During the past year (1924) the cohesion of soil colloids has been investigated by Middleton. The results† constitute a helpful addition to knowledge of the subject. Similar experiments on other soils are much needed.

* *Proceedings*, Am. Soc. C. E., March, 1922, Papers and Discussions, p. 523.

† *Journal of Agricultural Research*, Vol. 28 (1924), pp. 499–513.

Through the courtesy of R. L. Sackett, M. Am. Soc. C. E., a program of soil investigation is being formulated by the Engineering Experiment Station of the Pennsylvania State College.

There are many scientific institutions which through joint memberships are identified with the Society and to which the work of the Committee should appeal. The cost of the experimental work is small and with ample laboratory facilities available much would be accomplished toward reaching conclusions, even if only partial programs were undertaken.

To such an appeal A. T. Goldbeck, Assoc. M. Am. Soc. C. E., Chief of the Division of Tests, Bureau of Public Roads, U. S. Department of Agriculture, has responded with a useful contribution (Appendix II). The law he proposes is to be tested by field conditions. In the meantime, discussion is invited.

The Sub-Committee on Piling presents a progress report (Appendix III) and earnestly requests members of the Society to forward test data on piles.

In order to avoid delay in the work during his absence abroad, etc., the Chairman resigned from the Committee, but by the request of the Board of Direction, he resumed work on his return.

The outline of work for the coming year is a continuation of the study of cohesion of soils and of piling.

A vast quantity of data has been accumulated by the Committee requiring voluntary service for classification. Consequently, the Committee requests the Board of Direction to fill the existing vacancies and bring the membership up to the number of seven originally authorized.

Respectfully submitted,

ROBERT A. CUMMINGS,
Chairman.

March 6, 1925.

The Committee:

ROBERT A. CUMMINGS, *Chairman,*
WALTER J. DOUGLAS, *Secretary,*
E. G. HAINES,
ALLEN HAZEN,
J. C. MEEM,
GEORGE PAASWELL.

APPENDIX I

RECENT INVESTIGATIONS OF SOIL COLLOIDS

BY PHILIP L. GILE,* ESQ.

Recent Investigations Compared with Earlier Studies.—If a graph were constructed showing the interest soil scientists have had in the colloidal

* Chf., Div. of Chemical Investigations, U. S. Bureau of Soils, Washington, D. C.

material in soils at different periods, it would doubtless show peaks around 1855 and 1880 and a rather steep rise commencing about 1920.

In 1855, colloid chemistry was not yet born, but especial interest was being manifested in the investigations of Way (20*) and others on base exchange in soils. The property which soils have of adsorbing the base from a neutral salt solution and of releasing equivalent quantities of other bases was ascribed at that time to the presence of zeolites. It is now recognized that zeolites very rarely occur in soils and that this property is largely due to the colloidal material. It is interesting to note that recent studies on base exchange, which are similar in method to May's study and certainly no more thorough-going than his, are yielding new information about the soil largely because of the more correct idea now concerning the substances responsible for this phenomenon.

The peak of interest in soil colloids about 1880 is due chiefly to studies of Schloesing (18) and of Hilgard (10) on the mechanical analysis of soils and the behavior of the finest material they isolated. The very fine fraction isolated by Schloesing he called "argile colloidale". He believed that although only a very small amount of this material was present in soils, it was nevertheless responsible for most of the plasticity and coherence of the soil. Hilgard agreed with Schloesing that the plasticity of soils was due to a rather definite chemical substance, "a true clay substance". These ideas, that a rather definite substance of a colloidal degree of dispersion, present in small amounts, is largely responsible for properties of soils and ceramic clays, have been held rather generally until quite recently. It is now recognized that the colloidal material is not of definite composition and that it may form a large part of the whole soil.

The steep rise in the interest shown in soil colloids at about 1920 is believed by many to be the beginning of a period in which more and more attention will be devoted to these elements. In 1921 a symposium was held by the Faraday Society in London on the physico-chemical problems relating to the soil. In the papers presented at that time the prominence given to colloid conceptions is notable. In November, 1924, the American Society of Agronomy held a symposium which dealt specifically with soil colloids, and the American Soil Survey Association in 1924 also devoted part of its Annual Meeting to soil colloids. At the Second National Symposium on Colloid Chemistry held at Northwestern University in June, 1924, several papers were presented dealing with clays. These the writer has not yet seen. Bogue's recent book "The Theory and Application of Colloidal Behavior" contains a most interesting chapter on the Colloid Chemistry of the Soil by Professor Whitney of the U. S. Bureau of Soils (3). Increased interest in the colloidal material in soils is doubtless accentuated by the recent rapid development in pure colloidal chemistry.

Practically all the early work on soil colloids was conducted with the whole soil. The part that the colloidal material played in the phenomena was then inferred or assumed. There has been a notable tendency in recent investigations to deal with the colloidal material isolated from the remainder of the soil. This is particularly true of the work of the Bureau of Soils, U. S. Department of Agriculture. This new method of attack is yielding more definite and quantitative data than the old. It has been facilitated by the development of high-speed centrifuges for separating the colloidal material from the finer non-colloidal soil grains.

The Colloidal Fraction in Soils.—Many of those who have worked with the whole soil rather than with the isolated colloidal material have defined the soil colloidal material only in a general way. Hissink (11), for instance, refers to the colloid as the "clay-humus complex"; others define it as a "mixture of gels" or of "jelly-like materials". Such descriptions are informative regarding

* Numbers in parenthesis refer to the Bibliography attached to this paper.

the nature of the material, but are not sufficiently specific for quantitative studies of the colloidal material itself and are not satisfactory to soil engineers.

Some investigators who have isolated colloidal material, have defined it chiefly in terms of the procedure used in extracting it. Possibly this would be an adequate description of the material if the methods of isolation were perfect; but it seems to be acknowledged that the isolation of the finest separate obtained in most systems of mechanical analysis presents difficulties, and that variations in the method of analysis, particularly in the procedure used for disintegrating aggregates, may produce wide variations in the quantities of the clay or "Schlamm" separate.

In the investigations of the U. S. Bureau of Soils the colloidal material has been defined on the basis of size, all particles in the soil which are less than 1 micron (0.001 mm.) in diameter being classed as colloidal. This definition is fairly specific and forms a practicable, common basis for different investigations, since the size can be determined at 1 micron by long subsidence or by microscopic observation. The colloidal material as thus defined would be similar to the finest mechanical separate of European systems of soil analysis if, in the analytical procedure, all aggregates of particles less than 1 micron in diameter were dispersed or disintegrated.

One micron was more or less arbitrarily selected as the dividing line between colloidal and non-colloidal soil particles. However, investigations of the U. S. Bureau of Soils show that the bulk of 1-micron fraction in soils must consist of ultimate particles much smaller than this—less than 0.3 micron in diameter. The properties, both physical (2) and chemical (17), of the colloidal material are quite different from those of discrete mineral particles more than 1 micron in diameter. Thus, it is apparent that although the selection of 1 micron as the dividing line between colloidal and non-colloidal particles is arbitrary, nevertheless, when this arbitrary division is followed, the resulting fraction is at least preponderantly different, physically and chemically, from the material just larger than 1 micron. Of course, no matter what diameter is selected for demarcation between colloidal and non-colloidal materials there must be some small quantity of material in the colloid fraction which is of essentially the same physical and chemical nature as that of particles just larger than the critical diameter. The quantity of such material, however, should be less according as the limiting diameter is smaller, and apparently the quantity is small when the limiting diameter is set at 1 micron.

Estimating the Quantity of Colloidal Material.—The U. S. Bureau of Soils has recently devoted considerable attention to developing methods of estimating the total quantity of colloidal material in soils. The possibility of estimating the colloidal material from the properties of the soil by what might be called "ratio methods" has been discussed in several papers (1, 9, 15).

The ratio methods are based on two ideas: First, that the colloidal material in the soil is responsible for practically all of certain properties of the soil, such as adsorption, heat of wetting, and cohesion; and, second, that colloidal materials of different soils possess these properties in varying degrees. These ideas seem to have been verified by abundant data. If the adsorptive capacity, for instance, of the kind of colloidal material present in a soil is known, the colloid can be calculated from the adsorptive capacity of the whole soil; thus,

$$\frac{\text{Adsorption per gramme of soil}}{\text{Adsorption per gramme of colloid}} \times 100 = \text{percentage colloids in soil.}$$

An important and time-consuming feature of this method is the isolation of a sample of the colloidal material present in each sample of soil.

It has frequently been suggested in the past that an idea of the comparative colloidal contents of soils could be obtained by merely determining certain properties, such as the capacity for adsorbing a dye. The data presented by the U. S. Bureau of Soils, however, show the wide variation in properties of different

soil colloidal materials; hence the necessity of using the ratio method in this kind of determination.

Ratio methods were tried on thirty to forty soils, the percentages of colloid were estimated by adsorption of malachite green, adsorption of water vapor, and by heat of wetting. As a check on the ratio methods, the colloidal contents of some soils were determined by isolating all the colloidal material it was possible to extract and then determining undispersed colloidal material in the residue microscopically (6). This latter procedure called for the use of several hundred liters of water on a single sample of soil and the services of a person skilled in soil microscopy.

In the case of a few soils the agreement between all methods was very satisfactory. The Sharkey soils, for instance, gave 57% of colloid by malachite green adsorption, 61% by water adsorption, 59% by ammonia adsorption, 59% by heat of wetting, and 60 to 65% by combined isolation and microscopic count. In some cases, however, the agreement was as poor as 13%, 19%, and 22% by the three different adsorption ratios, 23% by the heat of wetting ratio, and 24% by combined isolation and microscopic observation.

The source of inaccuracy in the ratio method appears to be in the difficulty of extracting a representative sample of the colloidal material without affecting its properties. It appears that the ratio method based on adsorption of water vapor is usually the most accurate and that results obtained by this method usually approach the true value closely. This method can doubtless be improved to give strict accuracy.

None of these methods is recommended for routine work; they either lack the accuracy desirable in strictly quantitative work or they are too time-consuming. However, even as developed at present, they appear more accurate than methods suggested heretofore.

For routine work, pending the perfection of a more accurate method, the U. S. Bureau of Soils is estimating the colloidal contents of soils by determining the quantity of water vapor adsorbed by a soil over a 3% solution (by weight) of sulfuric acid. This necessitates the use of a thermostat in which the temperature does not fluctuate more than 0.1° cent. It was found that while the colloidal materials extracted from different soils varied widely in their capacities to adsorb water vapor over a 30% solution of sulfuric acid, they differed comparatively little in their capacities to adsorb water from the more humid atmosphere offered by a 3% sulfuric acid solution. Hence, a fair estimation of the quantity of colloid could be obtained by determining the quantity of water adsorbed per gramme of soil and then dividing by 0.3, which represents the average water adsorptive capacity of a large number of different soil colloids over a 3% solution of sulfuric acid (16).

The quantity of colloidal material in the soil probably varies from a trace to almost 100 per cent. Usually, loams contain from 20 to 25% of colloid; coarser textured soils contain less; and clays usually contain from 40 to 50%, although they may run much higher. A few soils that have been examined appear to be more than 90% colloidal material. These figures are not based only on determinations by ratio methods. From a sample of Houston clay soil 65% of colloidal material was actually isolated. By far the greater part of the isolated material was made up of sub-microscopic particles.

The Chemical Composition of Soil Colloids.—During the past year (1924), papers have been published on the chemical composition of soil colloids by Bradfield, of the Missouri Experiment Station (5), by Robinson and Holmes, of the U. S. Bureau of Soils (17), and by Joseph, of the Welcome Laboratories, Khartoum (12).

Bradfield concerned himself chiefly with the ultimate chemical nature of the colloidal material. He found that colloidal materials isolated from several Missouri subsoils were quite constant in composition and all more or less acid. The way the acidity varied on dilution and the forms of the conductivity and

acidity curves obtained on adding the material to dilute alkali led him to the idea that the soil colloidal material is a complex alumino-silicic acid (4). This evidence is not regarded as conclusive proof as to the nature of the soil colloidal material, since it has been pointed out that the reactions of the material can be equally well explained by the idea of adsorption compounds. The work of other investigators would indicate that if an alumino-silicic acid is a constituent of the soil colloidal material, other compounds are also present.

The work of Robinson and Holmes deals more with variations in the chemical composition of colloids isolated from different soils. Colloidal materials extracted from forty-five soils from different parts of the United States were analyzed. Wide variations in chemical composition were found, although several different soils yielded colloids that were much alike. The different colloids varied between 32% and 55% in silica, between 5% and 17% in iron, between 16% and 38% in alumina, between 1% and 17% in organic matter, and between 2% and 11% in the sum of lime, magnesia, soda, and potash.

The colloidal material is described as being the insoluble products resulting from the weathering of soil minerals. It is, therefore, quite different in composition from the mixtures of primary soil-forming minerals present in most soils. Some correlation was found between the rainfall to which a soil is exposed and the chemical composition and color of the colloidal material. Colloids with a high ratio of silica to iron and alumina were more frequently light colored, grayish, or blackish, and were obtained more often from soils exposed to the lower rainfalls. On the other hand, colloids with a low ratio of silica to iron and alumina were usually red, yellow, or brownish, and were obtained more frequently from soils exposed to the higher rainfalls.

Joseph analyzed the colloidal materials obtained from seven Nile soils, from four ceramic clays, and from two bentonites. He, also, found a wide range in the chemical compositions of the different colloids. Although he gives little data on the physical properties of the materials, he suggests that the physical properties of the colloids may parallel the silica to alumina ratio. Bentonite, which has the property of imparting plasticity to an exaggerated degree, shows a silica-alumina ratio of 7, while the colloid from a China clay has a ratio of 2.

Effect of Salts on the Colloidal Material.—Hissink, of Holland (11), and Gedroiz, of Russia (7, 8), for some years have been studying the replacement of bases that takes place when soils are treated with neutral salt solutions. The reactions are regarded as localized in the colloidal material, and there is no doubt that such is the case for the most part, although it has not been experimentally demonstrated. It has been shown, however, by Anderson and others (2) that 95% or more of the adsorption of malachite green by a soil is localized in the colloid, and this is evidently a base exchange reaction also.

Most of the work on base exchange in soils, which started with a very complete investigation by Way in 1850 (20), is primarily of interest with respect to soil fertility. Gedroiz, however, has recently shown that when some of the calcium and magnesium in the soil are replaced by sodium, the colloidal material is greatly altered (8). The alteration is evident in an increased swelling of the soil and in a greater deflocculation of the colloidal material after the excess of soluble salts is removed by leaching. Kelley (13) working with California soils has recently confirmed the results of Gedroiz.

This is quite an important discovery. Apparently, it explains the peculiar physical properties assumed by soils which at one time were impregnated with sodium chloride and sulphate, but no longer contain large amounts of these salts. It is believed to account for the impermeable character of certain soils in the arid and semi-arid West, which are locally known as "slick spots". According to experiments of Gedroiz, the enhanced swelling of the soil and dispersion of the colloidal material take place after the excess of soluble salts

is removed, the presence of considerable quantities of the sodium salts tending to keep the colloidal material in a flocculated condition. This would account for the poor physical condition produced by irrigating certain alkali soils.

Theoretically, the proper treatment for such spots would consist in replacing the adsorbed sodium by calcium, iron, or aluminum, since, according to Gedroiz, the substitution of these ions for the adsorbed sodium reduces the swelling and dispersion of the colloid. As a matter of fact, Scofield, of the U. S. Department of Agriculture, has had some success in improving the permeability of similar soils by treatment with aluminum salts (19).

Physical Properties of the Colloidal Material.—The U. S. Bureau of Soils is completing a study of the physical properties of colloidal materials isolated from a number of different soils. Many properties have been determined such as average size of particles, swelling, viscosity, electrical charge, heat of wetting, and the like. The properties of the different colloids vary widely, but it appears that most of the various properties are interrelated so that one property parallels another quite closely. A colloid, for instance, that shows a large change of volume on wetting usually has a high capacity for adsorbing ammonia and has a high heat of wetting.

An interesting feature of this investigation is that the physical properties of the different colloidal materials correlate fairly well with the chemical compositions. In some cases the relationship is almost quantitative. It appears, therefore, as though it would be possible to judge the kind of collodial material and its general behavior from one or two characteristic properties. Even the color may give a rough indication of what to expect of a given colloid.

During the past year (1924) a study on the cohesion of soils has been published by Middleton of the U. S. Bureau of Soils (14). This investigation touches a little more directly on soil engineering work than most soil research. A number of different soils were tested for cohesion by a standard method, which consisted in making the soils into briquettes under a pressure of 2 000 lb. per sq. in., drying slowly under controlled conditions, and then crushing in an Olsen Universal Testing Machine.

The compressive strength of the different soils varied from 2 to 75 kg. per gramme of soil. It was found that many factors entered into the strength of the soil briquette. Among the more important were the quantity of colloidal material, the kind of colloidal material, the size of the non-colloidal grains, and the original moisture content of the material.

The last factor, while not the most influential of the four in determining the cohesion of a compacted soil, is of interest to engineers inasmuch as it is frequently capable of at least partial control in consolidating soils. It was found that the moisture content which gave the densest briquette gave the strongest briquette. The optimum moisture content for making up the briquette varied from 11% for a fine sandy loam soil to 17.5% for a heavy clay soil. The optimum moisture content may vary with the pressure applied. This was not determined.

The great importance of the other factors in determining the cohesion of a soil is shown in the following data. The Stockton clay adobe colloid had twice the binding power of the Cecil clay loam colloid when mixed with quartz flour. The cohesion of mixtures increased with the percentage of colloid to a certain point. A mixture of coarse sand and 25% colloid had a breaking strength of 3.8 kg. per gramme, while a mixture of silt and the same quantity of colloid had a breaking strength of 24.6 kg. per gramme.

Significance of Soil Colloids to Engineers.—It seems quite apparent that investigations of the soil colloidal material will throw increasing light on problems that are of interest to civil engineers. The investigations published during the past year (1924) are of great importance in showing that the properties and behavior of a soil depend to a considerable extent on the kind of colloidal material present.

The quantity of colloidal material in a soil does not appear to differ greatly, as a rule, from the quantity of the old "clay fraction" given by various systems of mechanical analysis. It is now evident, however, that, in certain cases, the nature of the clay fraction (which is largely colloidal material) may be a more important factor in determining how a soil will act than the quantity of this separate. Further studies should show the kinds of soil colloidal materials which are most desirable for different types of work, such as earth dams, levees, foundations, and the like. Also, it should be possible to devise the proportions of colloidal material to different mixtures of non-colloidal soil particles which are best adapted to meet different conditions. These detailed relations obviously cannot be determined without a great deal of investigation, but it seems possible even now to characterize the different colloidal materials in a fairly definite manner.

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APPENDIX II

THE SUPPORTING VALUE OF SOILS AS INFLUENCED BY THE BEARING AREA.

By A. T. Goldbeck,* Assoc. M. Am. Soc. C. E.

Within the past few years a study of the properties of sub-grade materials under highways has become increasingly important. In recognition of this fact the United States Bureau of Public Roads has been attempting to develop tests on sub-grade materials that will be suitable for detecting the differences in their properties which are important from the standpoint of highways. These tests have already been described in detail.† In view of the probable importance of the test for bearing value, special investigations were made to learn something of the variables which affect the bearing value of soils.

It was early recognized that the bearing value of soil particularly for the rather small deformations permissible under rigid highways must vary considerably depending on the bearing area to which the load was applied. The bearing area of that part of a road surface which might be considered as being in active contact with the sub-grade and, therefore, aiding in supporting the load, is quite variable depending on a number of conditions. With a motor truck running along the edge of a pavement no doubt the bearing area is only a few square feet, whereas near the center of the pavement the area supporting the load is considerably greater. When the bearing value test is made in the laboratory it has been the custom to use a bearing area of only a few square inches. The question naturally arises as to what is the relation between these test results. The present discussion deals with tests which have been made to investigate the effect of the area on the bearing value.

Description of Experimental Methods.—The materials used in the present investigations consisted of mixtures of clay soil and Potomac sand sold commercially for use in concrete. Five distinct mixtures were used; the proportions of sand and soil were, respectively, 5 : 1, 5 : 3, 1 : 1, 1 : 3, and 0 : 1. The materials were moistened and mixed by hand, then placed in a test bin 6 ft. square and tamped in 6-in. layers to a total thickness of 30 in. The sides of the bin were constructed of planking, well braced, and the bottom was a concrete slab. A series of circular bearing blocks ranging in area from 1 sq. ft. to 9 sq. ft., were each loaded at a uniform rate by a hydraulic jack. Simultaneous readings of load and penetration were made by observing the movement of two Ames dials placed at each extremity of a diameter of the block. Load readings were obtained by observing deflections of a calibrated resistance beam. In using the larger blocks, the smaller blocks were pyramided one above the other in order to eliminate the possibility of appreciable bending in the bearing block.

* Chf., Div. of Tests, U. S. Dept. of Agriculture, Bureau of Public Roads, Washington, D. C.
† "Researches in the Structural Design of Highways by the United States Bureau of Public Roads", *Proceedings*, Am. Soc. C. E., April, 1924, Papers and Discussions, p. 453.

A series of smaller circular blocks, ranging in area from 1 sq. in. to 12 sq. in., was also tested. The test bin was emptied after each individual test and the material was loosened, replaced, and retamped. This was repeated a number of times with each area and with the different mixes. The moisture content was determined each day from representative samples taken at different depths immediately after the tests. The load was applied at a rate such that approximately 8 min. were required for full loading to a penetration of 0.1 in. In view of the fact that these tests were made primarily for road sub-grade conditions the penetration of the bearing blocks was not allowed to be very great, in no case exceeding 0.1 in. The loads applied were, therefore, rather small and the soils behaved in a rather elastic manner as will be seen in the load penetration curves, Figs. 1, 2, and 3. It is apparent from these three curves that, in general, the smaller the superimposed area, the greater is the unit of load required for equal penetrations.

From the data obtained curves were plotted for all the mixtures, showing the relation of the area of bearing block and the penetration, based on the load producing a penetration of 0.1 in. for the 9-sq. ft. bearing block. The curves for all soil mixtures were finally averaged, with results as shown in Fig. 4. The average experimental curve is quite closely approximated by the solid line having the equation: $y = 900x^2$, in which y is the area, in square feet, and x the penetration, in inches. From this relation it is seen that the penetration of bearing blocks of different areas varies as the square roots of the areas; that is:

$$\frac{p}{P} = \sqrt{\frac{a}{A}}$$

in which, p and P are the penetrations of bearing blocks having areas of a and A, respectively.

The conditions under which these tests were made should be carefully kept in mind for it is quite probable that this relation may be altered under conditions in which the sub-grade is not confined by the sides and bottom of the bin. Whether or not the relation will hold, it is, nevertheless, certain that whenever two different sized bearing areas are used, the larger bearing block will penetrate deeper than the smaller for the same intensity of load. The reason for this is not difficult to understand and may be explained by reference to the curves in Fig. 5. These curves were obtained in the U. S. Bureau of Public Roads about ten years ago by the use of a number of soil pressure cells buried in the floor of a test bin 10 ft. square filled with compacted damp sand to a depth of 54 in. The curves show the distribution of pressure at a depth of 54 in. under circular bearing blocks having areas indicated, all the blocks having the same load, 5 000 lb. per sq. ft. The important point to notice in these curves is that for a given depth under the blocks the intensity of pressure in the soil varies, depending on the size of the bearing block, the highest intensity occurring under the block having the greatest area. At other depths, similar curves could be plotted. Since the soil acts more or less elastically it follows that the higher the pressure the more will the soil be deformed. The penetration of a bearing block into the soil depends on the amount of deformation of the layers of soil placed under compression by the load on the bearing block. It is quite evident, therefore, that for corresponding intensities of load the large area must sink more than the small area because of the higher intensities of pressure and, therefore, the higher deformations produced within the supporting soil.

Arrangements have been made to continue these tests in a manner which will eliminate the confining action of the test bin both horizontally and vertically. It is thus hoped that data will be obtained to determine to what extent, if any, the law established in the laboratory might have to be altered when applied to field conditions.

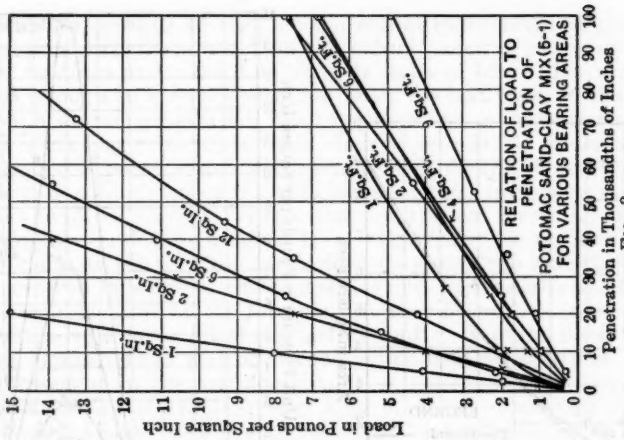

FIG. 3.

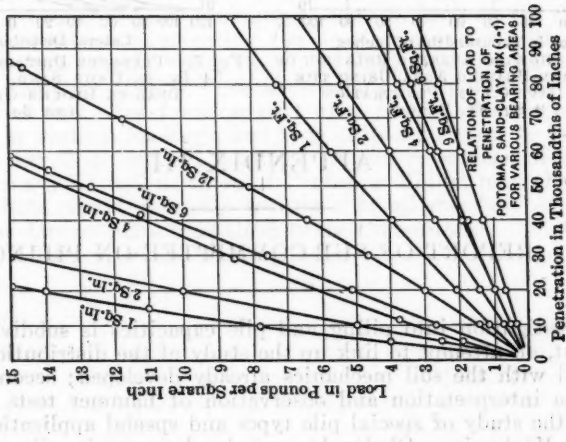

FIG. 2.

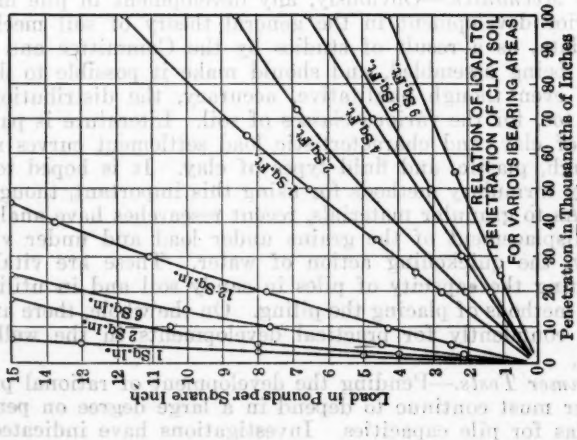

FIG. 1.

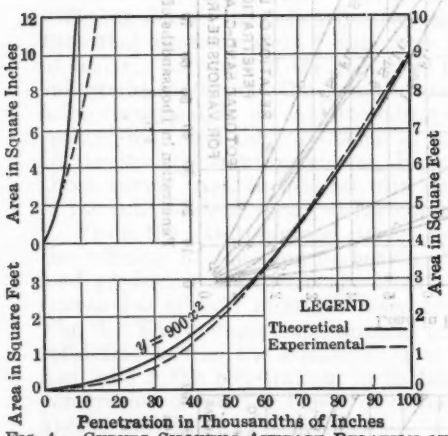

FIG. 4.—CURVES SHOWING AVERAGE RELATION OF PENETRATION AND BEARING AREA, USING THE LOAD THAT GAVE 0.1 IN. PENETRATION FOR A 9 SQ. FT. BLOCK.

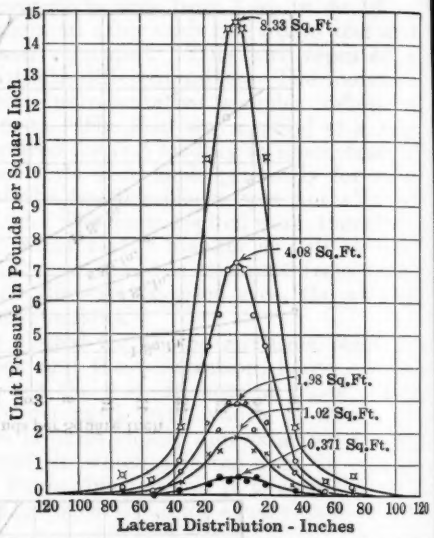

FIG. 5.—PRESSURE DISTRIBUTION AT A DEPTH OF 54 IN. IN DAMP SAND. VARIOUS CIRCULAR BEARING BLOCKS GIVING 5 000 LB. PER SQ. FT.

APPENDIX III

REPORT OF SUB-COMMITTEE ON PILING

The investigation into piling and pile capacities is subdivided into three parts: First, an attempt to link up the study of the distribution of pile loads through soil with the soil mechanics already developed; second, an improvement in the interpretation and observation of hammer tests while driving; and, third, the study of special pile types and special applications of the pile.

1.—Pile Mechanics.—Obviously, any development in pile mechanics must await a prior development in the general theory of soil mechanics. Some pertinent data, as a result of studies by the Committee and other investigators, are being assembled, and should make it possible to determine with reasonable, even though qualitative, accuracy, the distribution of the load at the pile toe, for the various classes of soil. Literature is particularly rich in studies of clay, and charactertistic load settlement curves may be drawn for the tough, plastic, and fluid types of clay. It is hoped to give definite and possibly formulary methods for using this important, though treacherous, material. As to granular materials, recent researches have analyzed the characteristic displacement of the grains under load and under vibrations and, particularly, the quickening action of water. These are vital factors both in determining the capacity of piles in sandy soil and in utilizing the most economical methods of placing the piling. On the whole, there are real reasons for hoping confidently for practical developments in the well named "pile mechanics".

2.—Hammer Tests.—Pending the development of rational pile mechanics, the engineer must continue to depend in a large degree on penetration tests and formulas for pile capacities. Investigations have indicated the need of

an autographic apparatus to register the actual movements of the pile head. The penetration formula is based on the actual penetration, or an average of such actual readings under the final blow, or series of blows. The inspector's eye is not quick enough to note the rebound under the last blow, so that it is quite possible that a shorter penetration, the net movement, is the only reading noted, and a higher bearing capacity is rated than is permissible under the formula. An autographic apparatus would eliminate such errors of observation. The introduction of a follower, or the splicing of a pile, introduce indeterminate factors that tend, in part, to vitiate the penetration formula. The relation between hammer and pile weights is a controlling factor in driving long wooden or concrete piles. Proper relations between drop and steam hammers have been evolved by some of the companies and such results should be incorporated in modifications of the formula. It may be well to point out that no single formula will cover all these factors and it is quite likely that developments in hammer tests will be toward better field observations rather than in an improvement in the mathematics.

3.—The necessity of avoiding very long piles has occasioned the introduction of the lagged pile. The placing of strips on a pile has proved efficient in many cases and a decided increase in bearing as well as a decrease in settlement has been noted. The subject is a broad one and it should not be a difficult matter to conduct an illuminating series of tests on the best methods of lagging and otherwise augmenting the bearing capacity without recourse to increasing the pile length. Both the U. S. Navy Department and the Dock Department of the City of New York have done pioneer work in this field.

Battered piles and piles forming part of a trestle bent are subjected to lateral as well as vertical loadings, and it is quite important to learn the soil resistance to other than vertical loadings. Some researches of Dr. Dörr of Karlsruhe, Germany, as well as those of Professor Möller, may prove useful.

The Committee would earnestly request that all members of the Society who possess test data on piles, send them to the Committee.

WATERWAY AND RAILWAY EQUIVALENTS

Discussion*

By William M. Black, M. Am. Soc. C. E.†

William M. Black,‡ M. Am. Soc. C. E. (by letter).§—In a long membership in the Society, it has been the writer's experience that the discussion brought out by a paper is frequently of equal or greater professional value than are the ideas presented by the author. Certainly the discussion on this paper is no exception to the rule, even though the points discussed are quite different from those anticipated.

It is evident that the writer was not entirely clear in his endeavor to formulate a criterion by which the economic necessity for a new transportation line should be judged. In the cases cited in the discussions, notably the improvement of the River Clyde, and the construction of the Manchester Ship Canal and of the Panama Canal, the benefits accruing from the completion of the project resulted directly from the creation of improved facilities for waterway transportation. It is equally true that pioneer work has been done in opening new lands for settlement, or in enabling National resources of timber or minerals to be utilized, by the creation of transportation facilities, by highways, railways, or waterways; but in all these cases the economic advisability of the works was carefully investigated before their inception and the costs were weighed as against the expected pecuniary returns. Even the old policy of European rulers of building railways along lines of strategic importance from a military, rather than from a commercial, standpoint was based on a supposed ultimate economy to the respective States. But are there not examples in the United States where, in past years, enthusiasts have succeeded in having large sums expended for transportation lines of all classes, which were not economically justifiable? Have efforts to this end yet ceased?

The discussion on the relative merits of waterway and railway transportation is interesting and figures of value are presented; but does any one believe that each transportation medium has not its own economic sphere, in the vast movements of natural and manufactured products required in the nation? Should not the question under consideration be how the total expense of the movement can be reduced, rather than the question of the earnings of this or that company? If, as on the Monongahela River, the use of the waterway

* Discussion on the paper by William M. Black, M. Am. Soc. C. E., continued from February, 1925, *Proceedings*.

† Author's closure.

‡ Maj.-Gen., U. S. A. (*Retired*); Cons. Engr. (Black, McKenney & Stewart), Washington, D. C.

§ Received by the Secretary, March 10, 1925.

diminishes the cost of production on a large proportion of the total output of one of the most necessary manufactured products, is not the required expenditure of public funds justified? In fact, the writer has been informed by one of the greatest producers of the Pittsburgh District that it could not have fulfilled the duty imposed on it and have done its allotted share of the work of the World War, had it not been for that improved waterway.

The transportation system of the nation is by no means economically perfect. Traffic does not follow natural lines; the railroad rate schedules are confessedly unscientific and needlessly cumbersome, causing discrimination against, and actual injustice to, many communities. The waterways have been developed only in parts, and the question of the economic adaptation of the carriers to the waterway channels has been too little studied. The highway system is new. The "common carrier" laws have an unequal application. The true co-ordination of all the transportation media is yet a dream of the future.

It is the belief of the writer that the full economic use of the highways, railways, and waterways can be achieved only when transportation is effected through duly supervised transportation companies and not, as to-day, by competing and more or less hostile, railway companies, auto-truck companies, and steamboat and barge lines.

DESIGN OF SYMMETRICAL CONCRETE ARCHES

Discussion*

By H. E. Warrington, M. Am. Soc. C. E.

H. E. Warrington,† M. Am. Soc. C. E. (by letter).‡—With respect to this valuable paper and to the discussion by Professor Cain§ concerning the assumptions used in determining the increase in loading on the arch in terms of the crown loading, the writer has compared two open spandrel arch ribs with the formula given. These arches have spans of 94 and 100 ft. In the case of the 94-ft. span, it was impracticable to obtain the loading per foot at the springing line of the arch, and, therefore, that obtaining at the last column (a point one-tenth of the span from the springing line) was used, of course, with its corresponding y.

For the other span, of 100 ft., the loading was computed at the springing line in the manner outlined by the author.‖ The comparison has been made both for dead load only, and for dead load plus one-half the live load. The results are as shown in Table 28. As will be seen, the loads as computed by the formula differ from the actual loads by a maximum of about 16%, being larger in one case and smaller in the other.

TABLE 28.—Relation of Actual and Computed Arch Loadings.

100-Ft. Arch.

Pt.	y.	Dead Load.			Dead Load Plus One-Half Live Load.		
		Actual, per linear foot.	By formula, per linear foot.	Percentage of actual.	Actual, per linear foot.	By formula, per linear foot.	Percentage of actual.
Crown.....	0.0	4 180	4 180	....	4 705	4 705	....
1	2.67	4 610	4 645	101	5 135	5 170	101
2	7.92	4 820	5 560	115	5 345	6 085	114
3	16.67	6 150	7 080	115	6 675	7 605	114
4 (Springing line)	30.00	9 400	9 400	....	9 935	9 985	....

* Discussion of the paper by Charles S. Whitney, M. Am. Soc. C. E., continued from April, 1925, *Proceedings*.

† Civ. and Structural Engr. (Warrington & Kromer), San Francisco, Calif.

‡ Received by the Secretary, March 16, 1925.

§ *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 422.

‖ *Loc. cit.*, November, 1924, Papers and Discussions, p. 1366.

TABLE 28.—(*Continued.*)

94-FT. ARCH.

Pt.	*y*.	DEAD LOAD.			DEAD LOAD PLUS ONE-HALF LIVE LOAD.		
		Actual, per linear foot.	By formula, per linear foot.	Percentage of actual.	Actual, per linear foot.	By formula, per linear foot.	Percentage of actual.
Crown.....	0.0	5 780	5 780	....	7 160	7 160	....
1	1.24	7 220	6 100	84.5	8 600	7 460	86.8
2	5.22	8 420	7 050	83.7	9 800	8 440	86.0
3	12.33	9 650	8 780	91.0	11 030	10 060	91.2
4	22.96	11 370	11 370	....	12 750	12 750	....
Springing line	37.50	.....	.....	....	.....	.....	....

Both arch ribs have a large rise ratio, 30% of the span for the 100-ft. arch, and practically 40% for the 94-ft. arch. For the latter arch, the co-ordinates of the rib axis differ from those required by Table 6* by only about 0.1 ft. For the 100-ft. arch the agreement is not so close; the maximum difference, however, is only about 0.3 ft.

The writer regrets that he could not compute the rib depths and the stresses therein by the formulas given in the paper, so that a fuller comparison might be made.

* *Proceedings*, Am. Soc. C. E., November, 1924, Papers and Discussions, p. 1369.

FLOOD FLOW CHARACTERISTICS

Discussion*

By Messrs. L. K. Sherman, George G. Honness, and L. M. Winsor.

L. K. Sherman,† M. Am. Soc. C. E. (by letter).‡—The data which the author has compiled and interpreted, are valuable contributions to engineering progress in the determination of rates of flood run-off.

In forecasting the run-off from relatively small areas the considerations of rainfall, time of flow, and coefficient of imperviousness (such as is used in storm-sewer design) will suffice. In forecasting flood run-off from larger areas, however, the results of actual observation must govern. The usual problem presented is the forecasting of floods from some particular drainage area which has few or no recorded run-offs. Such forecasting must be predicated on analogy with recorded data, such as Mr. Jarvis has presented. The question is how to interpret the existing data so as to apply to another water-shed.

Referring to observed run-off data, the four principal variants in the rate of flood run-off are:

1.—The size of the drainage area;
2.—The topography and surface characteristics;
3.—The frequency period for which any particular recorded run-off applies; and
4.—The rainfall characteristic.

If the recorded run-off is known for a water-shed identical in all four of the foregoing features with the new location, the problem is solved; but this is seldom the case. In order to apply the recorded data to a special case, it is important to know the relative values of these four principal run-off factors.

Size of Drainage Area.—The effect of this factor on the rate of run-off is quite well established; in larger drainage areas it is relatively small. The run-off rate increases as the area decreases.

Topography and Surface Characteristics.—The effect of these factors has been established only in a general way. In the light of present information, reliable results can be had only by gleaning out and utilizing data based on drainage areas of similar topography and surface characteristics.

Flood Frequency.—In any list of recorded run-off, this factor is the least certain, hence the apparent wide discrepancy in observed run-off from drain-

* Discussion of the paper by C. S. Jarvis, M. Am. Soc. C. E., continued from April, 1925, *Proceedings*.

† Pres., Randolph-Perkins Co., Chicago, Ill.

‡ Received by the Secretary, March 9, 1925.

age areas almost identical in size, physical character, and rainfall intensities. The author is to be commended in that, where possible, the part of the maximum flow which represents the average annual flood has been indicated in his table of flood records (Table 2*).

While it is true that the flood of 100-year frequency may occur within a year or two, there are many cases where it is poor engineering economy, if not impracticable, to build structures for an ultimate maximum possible flood. The extent of the investment in a structure for flood capacity is a matter of a comparative balance between the cost of insurance and that of flood damage.

It is important, therefore, to know the law of variation of flood frequency, not only for co-ordinating flood data, but also for determining the proper frequency to adopt in the design of any particular structure.

Weston E. Fuller, M. Am. Soc. C. E., has developed the law of flood frequencies.† Recently, Mr. S. L. Moyer, of Montevideo, Minn., presented a similar investigation of flood frequency.‡ Mr. Moyer has developed the expression, $Q = (c - d)e$, for the relation between the rate of run-off and the period of expectancy for such a rate. In the foregoing:

Q = the magnitude of flow, in cubic feet per second.

$c\,e$ = the limit to which Q approaches.

$$d = \left(\frac{1}{2f} + \frac{4.5}{f+8}\right)$$

in which,

f = the frequency or interval, in years, between peak flows of a given or greater magnitude.

In Fig. 9 has been platted the curve showing the relationship between run-off and frequency according to the Moyer formula when c and e were each unity. The law of frequency as expressed by Fuller reduced to the Moyer form, which is approximately, $Q = (0.99 - d)\ 0.8$, is also platted on Fig. 9 for comparison.

The curve shown dashed represents the recorded relation between the amount of rainfall and its frequency at Chicago, Ill. The point for the 22-year rainfall frequency has been platted arbitrarily to coincide with the 22-year point on the Moyer curve.

Both the Fuller and Moyer curves show the relatively rapid increase in the expected rate of run-off with slight increase in the frequency periods up to 10 or 20 years, the lesser increases from 20 to 40 years, and the slowest, almost straight-line, rate of increase after 40 years.

The dashed curve indicates what might be expected—the similarity between run-off intensity frequency and rainfall intensity frequency.

Rainfall Characteristic.—Rainfall is, of course, the prime factor in flood run-off. This factor, however, has the least variant (as between different

* *Proceedings*, Am. Soc. C. E., December, 1924, Papers and Discussions, p. 1563.

† *Transactions*, Am. Soc. C. E., Vol. LXXVII (1914), p. 564.

‡ "An Approach to Run-Off Expectancy", *Monthly Weather Review*, November, 1924.

water-sheds) of any of the four principal factors, namely, area, topography, frequency, and rainfall.

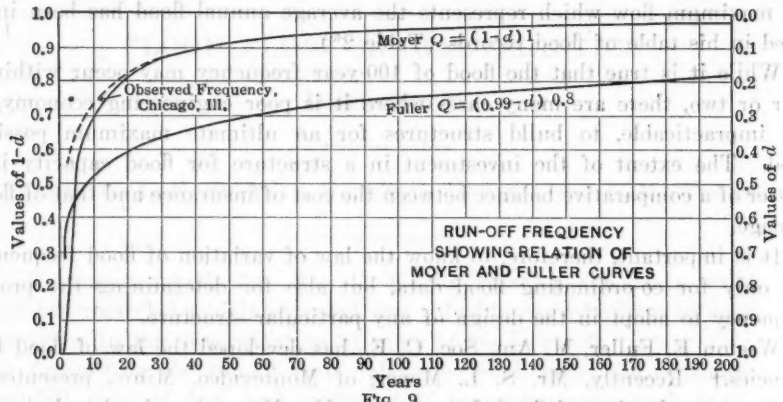
Moyer $Q=(1-d)1$
Observed Frequency, Chicago, Ill.
Fuller $Q=(0.99-d)\,0.8$
RUN-OFF FREQUENCY SHOWING RELATION OF MOYER AND FULLER CURVES
Values of 1-d
Values of d
Years
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

FIG. 9.

For a 20-year frequency, observations at twenty-two stations scattered throughout the United States show a general range within 2 to 3 in. of intensity of rainfall for 60 min. and a range within 7 to 9 in. of intensity of rainfall per hour for a period of 5 min. Meyers* has pointed out that more reliable results can be obtained by consideration of the rainfall data from a group of stations within a certain large area than from one particular station.

In the writer's opinion the chief value of a rainfall record in relation to any observed flood discharge, is its aid in determining the probable frequency period applicable to the flood in question.

Flood Height vs. Discharge.—Under this heading, Mr. Jarvis† has described interesting phenomena regarding flood waves and the channel regimen of certain streams. The writer has investigated the time of travel of flood waves in open channels.‡ In many situations a study of the height and velocity of flood waves on existing channels is of value in forecasting flood stages. Such investigation can determine how flood waves and velocities may be modified by changes in the channel section.

GEORGE G. HONNESS,§ M. AM. SOC. C. E. (by letter).‖—The author has performed a valuable service by so forcefully calling attention to conditions only too often neglected in the design of many engineering works and by supplying formulas which may be applied to all localities. These formulas, however, should be used with discretion so as to avoid uneconomical conclusions.

Little can be added by the writer except to furnish additional data which may be considered reliable for Northeastern United States.

On September 29 to October 1, 1924, inclusive, the Catskill Mountain region in New York State was visited by an unprecedented rainfall which

* "Elements of Hydrology."
† *Proceedings*, Am. Soc. C. E., December, 1924, Papers and Discussions, p. 1557.
‡ *Journal*, West. Soc. of Engrs., August, 1923.
§ Dept. Engr., Board of Water Supply, New York City, Grand Gorge, N. Y.
‖ Received by the Secretary, March 16, 1925.

led to flood discharges on the Schoharie and Esopus Creeks larger than any theretofore measured. A flood occurred in October, 1869, on Schoharie Creek, which is known to have exceeded the flood of September 30, 1924. At the time of the 1869 flood, it was said to have been the largest in the knowledge of the oldest inhabitants, and, therefore, it seems safe to assert that the flood of September 30, 1924, is the second largest in more than 100 years.

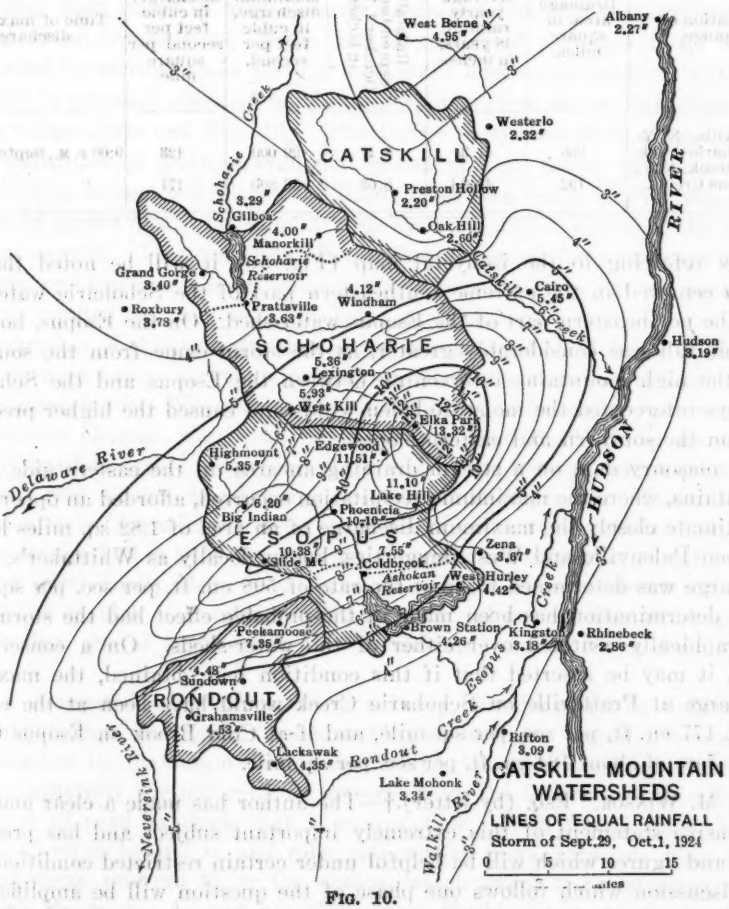

FIG. 10.

The storm began on September 29 and ended on October 1. For this period, 6.47 in. represented the average precipitation on the Schoharie water-shed above Prattsville (varying from 3.63 in. at Prattsville to 13.32 in. at Elka Park). On the Esopus water-shed above Cold Brook the average precipitation for the same period was 8.63 in., and varied from 5.35 in. at Highmount to 11.51 in. at Edgewood. The bulk of the rain fell on September 29 and 30, during a period of 36 hours.

In Fig. 10 is shown the region under discussion, together with the location of the rain gauges and the lines of equal rainfall for the period. Table 5 gives

essential data in reference to the locality and the storm of September 29 to October 1, 1924.

TABLE 5.—DETAILS OF WATER-SHEDS AND RECORD STORM.

Location of gauge.	Drainage area, in square miles.	Average yearly rainfall, 18 years, in inches.	Rainfall, September 29-October 1, 1924, in inches.	Maximum discharge, in cubic feet per second.	Maximum discharge, in cubic feet per second per square mile.	Time of maximum discharge.
Prattsville, N. Y., Schoharie Creek.	236	41.3	6.47	29 000	123	9:00 P. M., September 30
Cold Brook, N. Y., Esopus Creek...	192	47.6+	8.63	32 800	171	" "

By referring to the isohyetal map (Fig. 10) it will be noted that the storm centered in the extreme southeastern part of the Schoharie water-shed and the northeastern part of the Esopus water-shed. On the Esopus, however, the rainfall was considerably greater, as the storm came from the southeast and the high mountains intervening between the Esopus and the Schoharie Valleys intercepted the moisture-laden winds and caused the higher precipitation on the southern and eastern slopes.

A masonry dam on a stream draining an area on the eastern side of the mountains, where the maximum precipitation occurred, afforded an opportunity to estimate closely the maximum discharge of an area of 1.82 sq. miles located between Palenville and West Saugerties, known locally as Whittaker's. This discharge was determined to be at the rate of 508 cu. ft. per sec. per sq. mile.

A determination has been made of the probable effect had the storm been geographically centered over either of the water-sheds. On a conservative basis, it may be asserted that if this condition had obtained, the maximum discharge at Prattsville on Schoharie Creek would have been at the rate of about 177 cu. ft. per sec. per sq. mile, and if at Cold Brook on Esopus Creek, at the rate of about 184 cu. ft. per sec. per sq. mile.

L. M. WINSOR,* ESQ. (by letter).†—The author has made a clear and comprehensive statement of this extremely important subject and has presented facts and figures which will be helpful under certain restricted conditions. In the discussion which follows one phase of the question will be amplified and presented according to a somewhat different viewpoint from that of the author.

A distinction must be made between the two types of flood which appear in arid sections, in order to avoid confusion and to obtain a real appreciation of the actual conditions which confront the engineer in designing structures to handle this run-off.

There is a decided difference between the flood that comes as a result of melting snow, or excessive spring rain, and the raging torrent that follows a

* Irrig. Engr. in Chg. of Co-Operative Irrig. Investigations in Utah between U. S. Dept. of Agriculture and Utah Experiment Station, Logan, Utah.

† Received by the Secretary, March 21, 1925.

cyclonic storm in summer—what is generally known and perhaps erroneously termed a "cloudburst." Furthermore, there is as much difference in floods within humid and arid sections as there is in the appearance of the landscape. A flood in a humid country merely means the swelling of a stream beyond its normal volume. In a desert land a flood often means the appearance of a torrent where water had never been seen before.

Spring high water in arid climates is characterized by the swelling of a natural or an intermittent stream over a protracted period. If the flow is augmented by melting snow there is a constant fluctuation between night and day, with a constant rise and fall in total volume from day to day, depending on the temperature and humidity. Practically every mountain stream carries large quantities of drifting sand and gravel at high water, which cause an ever shifting stream bed within the limits of canyon walls, or over the entire surface of gravel cones and alluvial fans built by stream action at the mouth of every canyon. This condition often makes designing for waterways a most intricate problem and one to which run-off formulas have not yet been successfully applied for calculating probable requirements.

In streams of this type drifting gravel becomes the chief factor in designing waterways across highways, railways, and canal systems, or through towns and farming lands. Where attempts have been made to confine such a stream to a narrow channel, the result has invariably been the building up of this channel until it occupies the highest ground in the district, which makes the stream a real menace to adjoining property at flood periods. Under such a condition it is impossible to design bridges or culverts of sufficient capacity. As the stream bed is built up the opening across a roadway or under a canal is filled until finally there is no head-room left. Thus, a stream of a few second-feet in size, if it carries drifting sand and gravel, may cause greater trouble than one of 1 000 sec-ft. that carries only muddy water during flood periods.

The summer flood resulting from a heavy thunder-storm is different in every detail from the spring freshet or high-water flow. Usually, the summer flood reaches its maximum flow immediately. In other words, the very first wave is generally the highest. In extreme cases the breast of such a flood is composed of mud so thick that it cannot flow. It is forced along by the weight of water behind it, and rolls, rather than flows, forward. This is the type of storm referred to by the author, which swept the west slope of the Wasatch Range on August 13, 1923, from Nephi, Utah, on the south, to Brigham City on the north. It struck Nephi at 5:00 P. M. and at 8:00 P. M. had reached its northern limit 200 miles away.

It was not the quantity of water that caused the terrible destruction, but the manner in which it fell. It was such a storm as is frequent in tropical countries where probably 1 in. or 1½ in. of water falls in 10 min. In this case, however, it fell on soil and mountain steeps unprotected by tropical vegetation and unaccustomed to carrying the run-off from such a sudden and severe downpour. The result was inevitable. The entire upper foot in depth of soil in many areas was washed down into ravines and finally into the main canyon

leading to the country below. The conglomeration of soil, rubbish, and trees, mixed with a little water made a thick mortar which formed a dam in front of the flood, in places reaching a height of 50 or 60 ft. This dam was rolled forward when the accumulation of water behind it created sufficient pressure. The sliding and rolling mass of earth and débris literally swept the canyon clean of rock and vegetation, and, when released from the canyon walls, spread over the valley below, carrying houses, barns, orchards, livestock, and people to destruction.

The author shows (Fig. 4*) a huge boulder, 25 ft. high, which was swept along for 300 yd. In another instance, a large, modern dairy barn filled with hay was carried more than ¼ mile and landed in the main street of Willard, Utah.

In these floods, following the advance wave of mud, rubbish, and huge boulders, there came an after-flow of water which spread the débris to a certain extent; but the actual volume of water was negligible, except where it ponded behind the advance wall of mud.

Needless to say such floods have never been measured, nor will any theory of applied hydraulics as evolved in the laboratory aid in making an estimate as to the type, kind, and size of structure required to handle them. They are calamities which come once or twice in a lifetime under arid conditions, in mountainous regions.

In locating highways through desert regions this problem is ever before the engineer who is acquainted with the real flood conditions. There is no such thing as determining beforehand where or when the next flood will come. In many instances there is no such thing as a defined channel. In certain cases what appears to be a ridge may be the next flood channel. Close observation in desert regions will reveal the fact, usually, that the ridges at the foot of mountain slopes have been made by water.

Designing for such emergencies is a difficult problem and one which can hardly be accomplished by formulas. It is recommended, therefore, that application of the author's deductions be confined to established waterways and living streams, rather than to desert areas which are subject to heavy summer floods.

It is also important that the engineer who is unacquainted with the character of floods in desert lands, give proper weight to the information available from natives who are familiar with the territory through which roads or canals are to be built.

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* *Proceedings*, Am. Soc. C. E., December, 1924, Papers and Discussions, p. 1551.

HYDRO-ELECTRIC POWER AS A BY-PRODUCT OF AGRICULTURAL STORAGE

Discussion*

By L. T. Guy, Jun. Am. Soc. C. E.

L. T. Guy,† Jun. M. Am. Soc. C. E. (By letter).‡—This interesting outline, of the problems usually encountered in hydro-electric developments in the United States, has led the writer to believe that a short account of a similar project in Australia may be of interest to members. This project is situated in the State of Victoria, Australia, and is known as the Sugarloaf-Rubicon Scheme, its construction having been authorized by Parliament.

In Victoria, irrigation and electric supply are controlled by independent Government authorities. The Sugarloaf Dam, which is now approaching completion, is being constructed by the Irrigation Authority, and is of the rock-fill type with concrete core-wall. The river bed at the dam site is about Elevation 703, and the present construction comprises the impounding of water to Elevation 823, with a storage capacity of 300 000 acre-ft., provision also being made for an increase in height of full water level to Elevation 875 at some future time. It is proposed to locate the power station immediately below the dam.

The construction of the Sugarloaf Dam has been undertaken primarily for irrigation, and it is not proposed to charge any part of its cost to the electric supply undertaking. It is thus clear that the Electric Supply Authorities have no control over the discharge from the storage. The water discharged from the dam is not passed immediately to irrigation, but flows down the river for a distance of about 200 miles to a further regulating basin whence it flows by gravity to the land to be irrigated. There is thus no irrigation pumping load.

The irrigation season in Victoria extends in general from December to the following April, and water may possibly be passed during May. During this period, with the present storage capacity, it is proposed to maintain the irrigation flow at 833 sec-ft. continuously; however, the great distance between the dam and the actual offtake for irrigation is important, in that it will allow of the flow of water being varied throughout the day to follow the power load somewhat, provided the average daily flow is 833 sec-ft. After May, the

* This discussion (of the paper by Everett N. Bryan, Assoc. M. Am. Soc. C. E., published in January, 1925, *Proceedings*, but not presented at any meeting of the Society) is printed in *Proceedings* in order that the views expressed may be brought before all members.

† Senior Asst. Civ. Engr., State Electricity Comm. of Victoria, Melbourne, Victoria, Australia.

‡ Received by the Secretary, March 25, 1925.

outlets of the reservoir will be closed to allow the reservoir to fill in readiness for the following irrigation season and the outlets will remain closed until full supply level is reached, which will normally occur about July or August. From then until the commencement of the next irrigation season, the reservoir is spilling continuously and the whole of such flow may be utilized for the generation of power.

It is thus obvious that for about three months in each year no power would be available from a power station situated at this dam, and although this station is interconnected with steam power stations of larger capacity it would not be feasible to develop such a plan, unless some economical means could be devised to bridge over this gap each year during the winter months of May, June, July, and sometimes August, or even later.

Investigation disclosed the existence, within a few miles of the Sugarloaf Dam, of considerably smaller mountain streams, which could be developed as high-head plants and which reached their maximum flows during the months when power was not available from the Sugarloaf Dam. Conversely, the minimum flow of these streams occurs when power is available from the Sugarloaf Power Station, and although this minimum flow is considerably less than the proposed capacity of these plants, sufficient storage is obtainable at the intakes to serve as daily pondage. It will thus be possible to regulate the minimum daily flow so as to obtain the full output of the plant during the hours of peak loading. The total installed plant proposed on these mountain streams is 22 000 b.h.p. The auxiliary power, although relatively cheap, is naturally more expensive than that developed at the Sugarloaf Dam, but the combination enables a continuous supply of electric energy to be maintained at a favorable rate.

Gaugings are available at the Sugarloaf Dam dating from 1882—an exceptionally long period for Australia—and this has enabled careful consideration to be given to the size of plant to be installed, by the preparation of close estimates, both as to cost and power.

The exact size of the installation is not yet determined, but it will probably be about 12 000 b.h.p. This capacity may, at first sight, sound excessive when it is considered that the regulated flow of 833 sec-ft. under the maximum head will produce only about 8 500 b.h.p. This increase is justified, however, by the large volume of water which is spilled from the reservoir during the months of August, September, October, and November, and is all available for power generation.

This enables additional kilowatt-hours to be generated at a total cost less than the actual cost of coal required for the generation of similar power at a steam station.

Another problem encountered in a plant of this nature is the great range of head under which the turbines are required to operate. At Sugarloaf Dam the net head for the present height of dam varies between 60 and 115 ft.; a turbine with a satisfactory efficiency curve over this range should be obtainable. After the reservoir is raised to its ultimate stage, the net head will vary from 60 ft. to 165 ft., and this will probably involve changing the runners twice each year, with the varying head.

SHERMAN ISLAND DAM AND POWER-HOUSE

Discussion*

By Messrs. Eugene E. Halmos, J. C. Meem, George A. Orrok, Lazarus White, Thaddeus Merriman, Henry Goldmark, Byron E. White, B. F. Jakobsen, Charles W. Comstock, and Walter H. Wheeler.

Eugene E. Halmos,† M. Am. Soc. C. E.—In his paper the author has presented a complete description of the structures of the Sherman Island Development and several articles in engineering periodicals have given elaborate accounts of the methods of construction. There is little, therefore, to be added. This discussion will be confined to the design of the coffer-dams in which the main dam was built and show its correlation with the general program of construction and with the flood characteristics of the Hudson River.

The magnitude of the project indicated a period of construction extending over approximately two and one-half years, allowing two seasons for the construction of the main dam. It was decided to construct the dam in two sections beginning with the northern part. As soon as the spring freshets of 1921 receded, the first coffer-dam was to be built adjoining the north shore, leaving the southern unobstructed part of the river bed to carry the flow. The completion of the dam in this first coffer to Elevation 337, was required by February, 1922. Immediately thereafter, and before the expected occurrence of the 1922 spring floods, the sheet-piles of the first coffer were to be pulled and later re-driven after the 1922 freshets had receded, to form the second, southerly, coffer-dam. During this second season of building operations the dam in the second coffer was to be constructed and the part built in the first coffer topped off, while the flow of the river was to pass through the openings provided for this purpose between the buttresses of the first part of the dam.

The basis of the design, therefore, consisted in fixing the length and height of the first coffer-dam so as (1) to leave an unobstructed waterway to discharge the maximum summer flood; and (2) to construct a sufficient number of bays within this dam for the discharge of a similar summer flood after the second coffer-dam had been built to the same height, thus closing the waterway.

The calculations were based on the available data, consisting of fairly complete flow records, a rating curve for the dam site, and a cross-section of the river. The orifice formula was used to determine the discharge capacity of the sluices in the dam, the coefficients being taken from the results of

* This discussion (of the paper by H. de B. Parsons, M. Am. Soc. C. E., published in March, 1925, *Proceedings*, and presented at the meeting of the Society on March 4, 1925), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Chf. Engr., Parklap Constr. Corporation, New York, N. Y.

measurements on the sluices of the Assuan Dam. The submerged weir formula was applied to the open sections and the effect of back-water was given proper consideration, following a trial-and-error method, until a perfect balance was obtained. The crest of the coffer-dam was set at Elevation 317.5, which is about 22 ft. above the general level of the river bed. In the first coffer, a length of about 350 ft., was necessary to permit the construction of 16 bays giving the required carrying capacity for the discharge of 36 000 cu. ft. per sec., the maximum summer flood on record, with 6 in. of free-board at the up-stream line of sheet-piles. The same carrying capacity for the same height of water level was provided in the 140-ft. open waterway between the south end of the first coffer and the south shore of the river. Fig. 20 shows the discharge capacity of the openings in the dam and of the open waterway, for different water elevations up stream from the coffer-dams. The sheet-piles were 45 ft. long along the up-stream line and 35 ft. along the down-stream line, one-half the length being driven into the river bed. They gave an excellent water seal and occasioned no difficulty in keeping the coffer-dams free of water for working purposes.

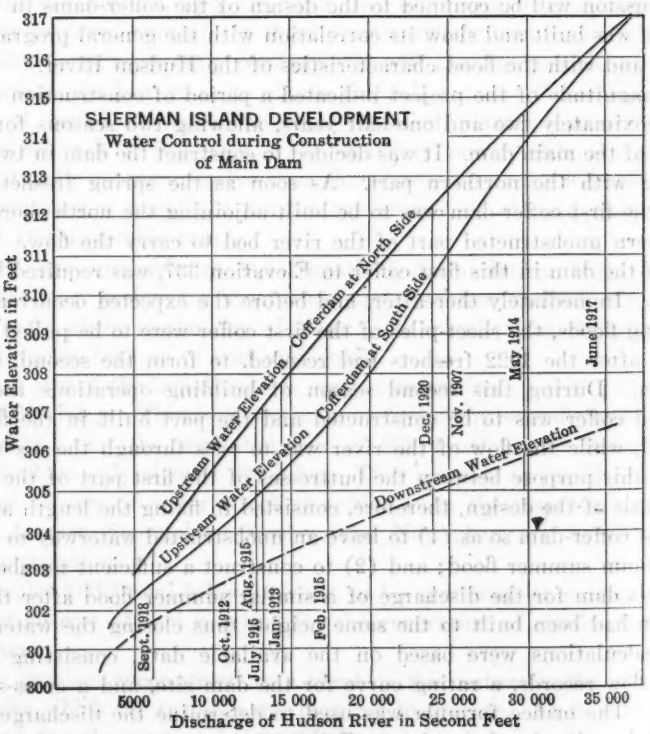

FIG. 20.

It was also estimated that with the openings in the northern part of the dam available for flood discharge plus the capacity of the open waterway, the height of the water above the dam for a flood of 100 000 sec-ft. would not have

been over Elevation 330. This head was thought to be the maximum to which the dam could be safely subjected without using the up-stream and down-stream fills to lend additional weight and stability to the structure. The actual discharge of the 1922 flood reached a maximum of 56 000 sec-ft., raising the water behind the dam to Elevation 322.

The original program was carried out to the letter except that the up-stream row of piling in the coffer-dam was not pulled, but instead was cut at low-water elevation so as to provide an additional cut-off. The dam was ready for the final closing operation by the end of 1922. This final closing, however, was considered to be such a delicate operation, and involved the other structures of the development to such an extent, that plans were made for its execution as early as August, 1922. These plans were based on assumptions of expected weather and flow conditions and were flexible enough to be changed to conform to the actual conditions prevailing at the time of closure. Fig 21 shows the discharge capacity of the openings in the main dam and in the spillway dam, which were provided to control the elevation of the pond during the operation of closing.

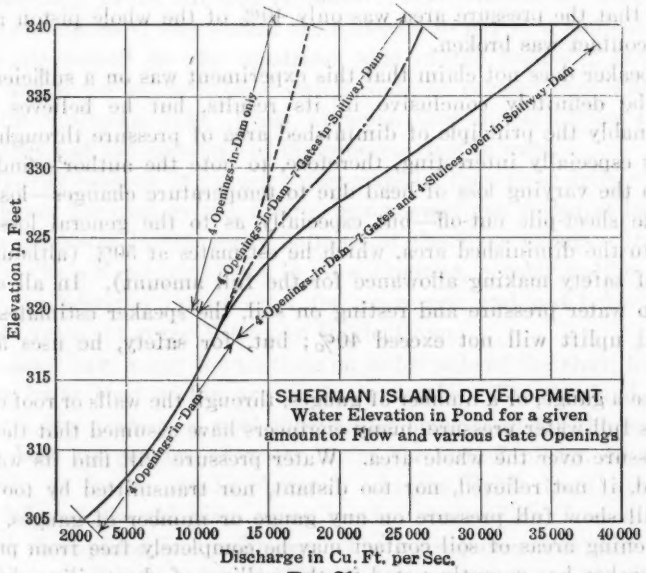

FIG. 21.

The time of the actual closing was delayed on account of the extreme cold weather in January and February, 1923; the first water went over the spillway dam on March 29, instead of March 1, 1923, as originally contemplated.

J. C. MEEM,* M. AM. SOC. C. E.—The speaker has been greatly interested in this paper and more especially in that part of it relating to uplift.

It appears that the author has given a large measure of concise, definite, and practical information on this interesting subject. For some years the

* Vice-Pres. and Chf. Engr., Frederick L. Cranford, Inc., Brooklyn, N. Y.

speaker has been interested in this question, often misunderstood, and has made, in a small way, some experiments and investigations concerning it and its allied subject—water pressure through soil. It is believed that the following may be pertinent, even though some of it has appeared before in the *Transactions* of the Society.

In a paper* read before the Society on May 18, 1910, the speaker described an apparatus and method for measuring the uplift through soil, which, briefly described, consisted of a hydraulic chamber connected by copper tubing with a pump and gauge. Projecting into this chamber, through hydraulic packing, was a piston 2½ in. in diameter. With the piston plunged about 6 in. into water, partly filling the chamber, it was found that a gauge pressure of approximately 8½ lb. was required to overcome its weight and the small frictional resistance.

With the piston plunged into sand carrying an additional head of water of 2 or 3 in., it was found that after it had stood for about 2 hours, it required approximately two and one-half times the pressure, or nearly 22 lb. (average), to start it, after which the pressure fell to 8½ lb. as before. This apparently indicated that the pressure area was only 40% of the whole piston area until the sand contact was broken.

The speaker does not claim that this experiment was on a sufficiently large scale to be definitely conclusive in its results, but he believes it shows unquestionably the principle of diminished area of pressure through soil.

It was especially interesting, therefore, to note the author's findings, not only as to the varying loss of head due to temperature changes—loss of head due to the sheet-pile cut-off—but especially as to the general loss of pressure due to the diminished area, which he estimates at 50% (although in the interest of safety making allowance for the full amount). In all structures exposed to water pressure and resting on soil, the speaker estimates that the theoretical uplift will not exceed 40%; but, for safety, he uses 50% as a factor.

Because a gauge, or a number of gauges, through the walls or roof of a structure shows full water pressure, many engineers have assumed that there is full water pressure over the whole area. Water pressure will find its way to any orifice and, if not relieved, nor too distant, nor transmitted by too tortuous a way, will show full pressure on any gauge or number of gauges, although the intervening areas of soil contact may be completely free from pressure.

The speaker has recently noted in the pulling of sheet-piling driven to a penetration of more than 30 ft. below the bottom in tidal water and into a dense soil containing a mixture of blue clay and fine sand, that, in many instances, the piling came up with large lumps of soil adhering to it, some of the masses being in excess of 1 ft. in thickness, with their interiors more or less dry. This indicates that water which does not have an outlet, is excluded from soils somewhat in proportion to their densities.

The soil in question is similar in texture to that underlying the Hudson River and is often classed as quicksand, because of its tendency to become "soupy" under hydraulic action.

* "Pressure, Resistance, and Stability of Earth," *Transactions*, Am. Soc. C. E., Vol. LXX (1910), p. 352.

The fact that structures resting wholly on soil do not have water pressure over their full area should not be confused with the pressure through soils against structures resting on piles or caissons, which may be subject to full pressure over all areas not in contact with the piles or caissons. This was especially noted in the case of the dry dock at the Brooklyn Navy Yard, which is largely supported by wall caissons.

The value of the pile cut-off is clearly demonstrated in this paper; but apparently there should be no question as to its necessity. The impounded water must find an outlet to and through which seepage may occur. Without the pile cut-off, this seepage might develop slow erosion, eventuating more or less disastrously, whereas, with the cut-off in place, greatly reduced seepage continues, as shown by the pipe tests; but erosion cannot occur, and it is probable that in time the seepage may be further reduced or entirely prevented.

GEORGE A. ORROK,* M. AM. SOC. C. E.—This paper shows once again the essential tightness of hardpan to resist the percolation of water. Engineers learned this early in the building of dams. They were taught to cut a trench across the stream until they struck the hardpan, to put in a mud-sill, to drive the sheet-pile cut-off on the up-stream side of the mud-sill, and to erect A-frames and a wooden structure, which could be covered over with sand or loam on the up-stream side. Thus, although they did not know the use of concrete, they had the prototype of the concrete dam in wood.

Glacial drift hardpan is a much better material than river drift. The latter material is not hardpan by any means, being sometimes found at least 100 or 200 ft. in thickness in the rocky bottoms of the river valleys. It has been bridged over in a number of dams in New England, notably on the Shetucket River, by the Scotland Dam built a few years ago, and just below it by one probably 45 years old at the Village of Baltic, Conn.

These dams have rocky foundations on either side of the river, but none at the center, or at least within any ordinary depths. The Scotland Dam was built only a few years ago, steel sheet-piling being used for the cut-off; and there has been no passage of water under the cut-off piling, on the down-stream side, as far as can be observed. At the Baltic Dam, however, the builders followed the old plan, using wooden sheet-piling, because, in those days, steel sheet-piling was unknown. The consequence was that the water followed the cut-off in the river drift on the up-stream side of the piling until it got below it, and passed up on the down-stream side washing out the foundation, resulting in a large hole on one side of the dam and the emptying of the pond.

This was corrected by using a sheet-piling that went down 7 ft. farther, and an attempt at grouting, which, in those days, was not a very great success. Seventeen years ago that second piling went out, but not in the same place as the first. Then the engineers did what they should have done in the first place—they placed a proper cut-off along the whole length of the dam; they went down to about 45 ft. To date, that cut-off has given good service.

* Cons. Engr., New York, N. Y.

LAZARUS WHITE,* M. AM. SOC. C. E.—The Engineering Profession is indebted to Mr. Parsons for the experiments and investigations made in connection with building a dam on sand foundations, and for his clear exposition of the problems involved; also, of course, to those who had the courage and faith to finance the construction.

Of particular interest are the observations and data bearing on uplift pressures. The subject of uplift beneath dams has been discussed to the speaker's knowledge for the past twenty-five years, and estimates on its value have varied from 100% of the theoretical downward. It is evident that it must be much less than 100% or a great many existing dams would not now be standing. Mr. Meem, in his discussion, refers particularly to his experiments as published in his paper entitled "Pressure, Resistance and Stability of Earth."† These experiments, which are still the only good ones, demonstrate that the upward pressure is in proportion to the voids in the sand. As he did originally (1910), Mr. Meem again calls attention to the need of further experiments on a larger scale.

It is surprising that these have been the only tests, considering their great value and the need of conclusive data on this point. For lack of precise information many structures have been extravagantly designed. It would appear that by a relatively small expenditure, this problem could be solved.

An interesting feature of the paper is the information given on the effect of steel sheet-pile cut-offs and on the variation in uplift on a dam between winter and summer. This may be explained by the viscosity of water, which property is more important than is ordinarily considered. As water becomes denser with lower temperatures, the viscosity necessarily increases, thus counteracting the hydrostatic effect of the water contained within the grains. Water flowing in small spaces acts like a glue, causing great loss of head.

The true value of uplift is of great importance in the design of coffer-dams, as, for instance, where steel sheet-piling is driven in a river bed of sand, the material dredged out, and a concrete blanket placed by tremie to allow the subsequent pumping out of the coffer-dam. What thickness of blanket is to be used? The full theoretical pressure for a 40-ft. head would require a blanket almost 20 ft. thick, whereas a blanket less than 10 ft. thick has been shown by experiments to be ample. Because of lack of precise data on this question, much concrete is wasted. The excess of concrete in a single coffer-dam would pay for the experiments necessary to clarify the whole subject.

THADDEUS MERRIMAN,‡ M. AM. SOC. C. E.—It has been most instructive to study this paper because it so clearly describes a work which was done under difficult and trying conditions. Certain features are particularly worthy of discussion. Among them is the tabulation on page 348,§ which discloses the surprising fact that the greatest known flood occurred in 1913—within the lifetime of a small boy. No record of the greatest unknown flood is presented. The only certainty in regard to flood records is that they are all sure to be

* Pres., Spencer, White and Prentis, Inc., New York, N. Y.
† *Transactions*, Am. Soc. C. E., Vol. LXX (1910), p. 352.
‡ Chf. Engr., Board of Water Supply, City of New York, New York, N. Y.
§ *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions.

exceeded. The largest known flood is always the one which is displaced from its high position on the list. Few, if any, flood-flow records have even the respectability of middle age. Nearly every day, in some part or other of this fair land, there occurs an unprecedented flood, leaving behind it desolation and destruction. The present tendency seems to be that of concentrating all kinds of detailed analysis on such meager data as are available, in the effort to predict what the future may bring forth. This procedure naturally results in the exclusion of both judgment and vision. The records left on the face of the topography by the great floods of the past are seldom, if ever, included in the computations on which the predictions for the future are predicated.

The cross-section of the dam site (Fig. 3*) is incomplete to the extent of not showing where the rock lies under the central part of the structure. If there is a record of this depth, the author may well include the figures in his closure, not only for the purpose of enabling a better understanding of all the conditions at the site, but also as a contribution toward the general knowledge of the depth to which these rivers cut their valleys before the coming of the glaciers.

The author has referred† to the movement of the dam both vertically and horizontally in a down-stream direction as the load of the water came on it. The data presented are interesting and instructive. Buttress No. 6 apparently settled vertically 0.40 in., notwithstanding the fact that it was founded on rock. Now this 0.40 in. may represent either shrinkage or compression of the concrete, or both. The author has not referred to this possibility and neither has he made mention of the cracking of the concrete which the settlements and lateral movements as recorded would seem to indicate. Referring to the motions which have taken place, he states that they show little change in either settlement or alignment, and that the dam appears to be at rest with the exception of changes due to temperature. If there are any data available on the effect of changes due to temperature, the author will perform a most valuable service by presenting them, because the ultimate life and integrity of nearly all engineering structures are, in great measure, dependent on the daily and seasonal motions which result from ever-recurring temperature changes.

The profile in Fig. 18‡ shows very clearly the variation in pressures from the line of the cut-off down to the tail-water, while Fig. 19§ shows the fluctuation in uplift pressure as observed in different seasons. The author's second conclusion from the data presented is to the effect that an increase in the temperature of the water, having the effect of decreasing the resistance to flow through the sand, not only increases the velocity, but also decreases the loss of head. With this the speaker does not agree and presents the following hypothesis.

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* *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 345.
† *Loc. cit.*, pp. 354-355.
‡ *Loc. cit.*, p. 371.
§ *Loc. cit.*, p. 372.

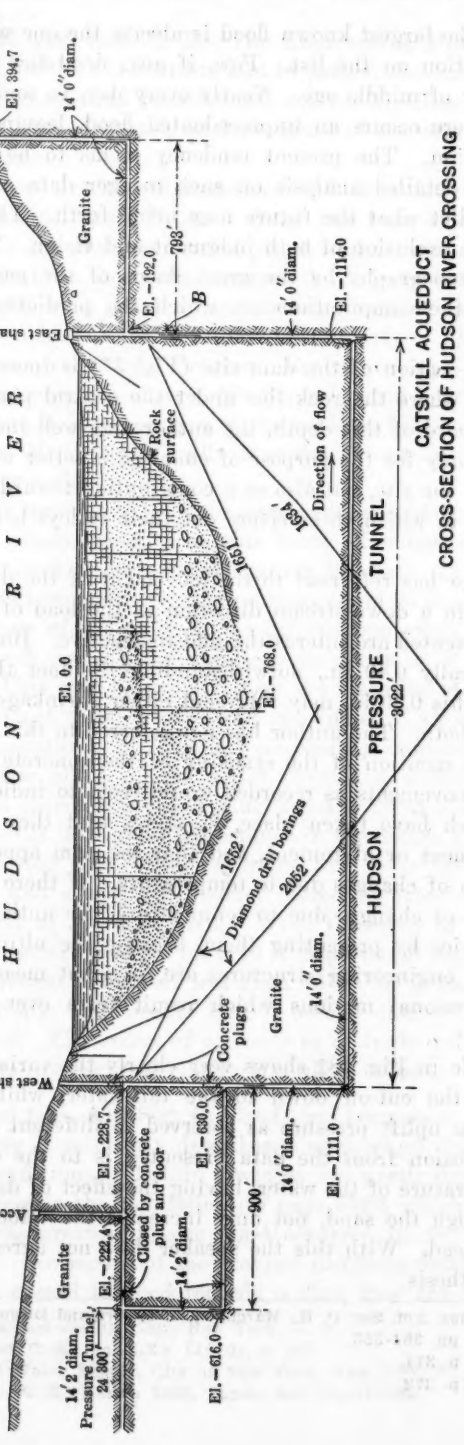
CATSKILL AQUEDUCT
CROSS-SECTION OF HUDSON RIVER CROSSING
LOOKING NORTH
HUDSON RIVER
Grade tunnel
El. 394.7
14′ 0″ diam.
Uptake shaft
Granite
El. −192.0
793′
B
14′ 0″ diam.
El. −1114.0
East shaft
Rock surface
Direction of flow
1634′
1651′
TUNNEL
PRESSURE
8022′
El. 0.0
El. −768.0
1652′
Diamond drill borings
2052′
HUDSON
14′ 0″ diam.
Granite
Concrete plugs
West shaft
El. −228.7
El. −630.0
Closed by concrete plug and door
14′ 2″ diam.
14′ 0″ diam.
El. −1111.0
Access shaft
Granite
El. −222.4
900′
14′ 2″ diam. Pressure Tunnel, 24 300′
El. −616.0

FIG. 22.

As the temperature of the water rises the volume of each sand grain increases and the volume of the voids is correspondingly decreased. In the smaller passages thus formed the static pressures would necessarily rise, it being assumed that the head of water in the pond remains constant. Conversely during the winter season, the voids in the sand are at their maximum. The water then flows with more facility and the uplift pressures decrease. A lowered hydraulic gradient, as shown by the pressure pipes, indicates that either less water is finding its way into the sands or that the loss of head within the sand has been reduced. There is no information available as to changes in the quality of leakage from summer to winter, but the speaker is willing to hazard the estimate that the leakage through the sand is greater in winter than in summer notwithstanding the greater viscosity of the water due to the lower temperature. The so-called uplift pressure is not a direct index of the quantity of water which passes under the dam. The leakage must be in inverse proportion to the uplift pressure.

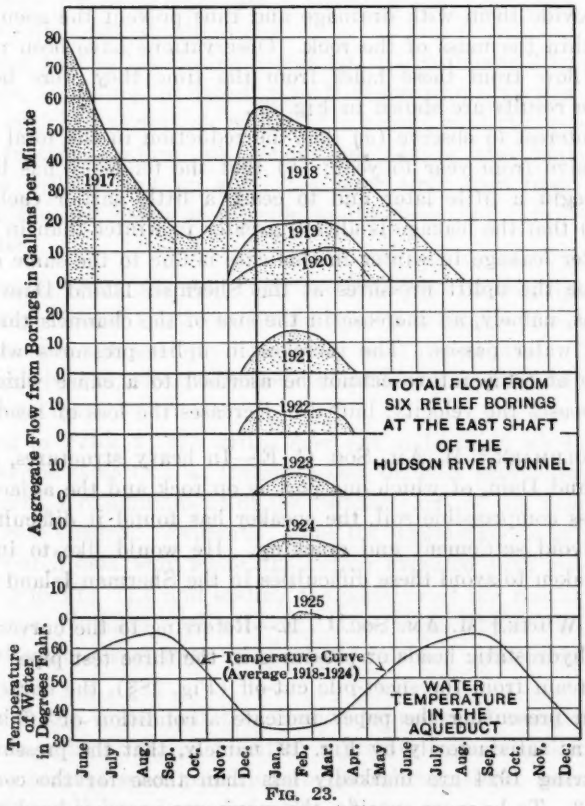
Aggregate Flow from Borings in Gallons per Minute
1917
1918
1919
1920
1921
1922
1923
1924
1925
TOTAL FLOW FROM SIX RELIEF BORINGS AT THE EAST SHAFT OF THE HUDSON RIVER TUNNEL
Temperature of Water in Degrees Fahr.
Temperature Curve (Average 1918-1924)
WATER TEMPERATURE IN THE AQUEDUCT
June July Aug. Sep. Oct. Nov. Dec. Jan. Feb. Mar. Apr. May June July Aug. Sep. Oct. Nov. Dec.

FIG. 23.

Nearly all experiments on the flow of water through sands have been made under conditions in which the sands themselves were not confined within a definite volume. In the case under discussion there is a body

of sand on which is placed a large dam with much weight of water above it. In a filter bed the upper surface of the sand is always free to move as the sand grains change their volume with changes in temperature.

On Fig. 22 is shown a cross-section of the Hudson River at the point where it is crossed by the Catskill Aqueduct Tunnel. Shortly after the tunnel was filled with water to the hydraulic gradient, which is 425 ft. above the river surface, a series of cracks developed in the concrete lining of the shaft near the point marked *B*. These cracks were the result of rock movement caused by the escape of small quantities of water into the joint planes of the rock. In this manner pressure was applied over large areas and the rock moved. The action was analogous to the well-known use of compressed air for the quarrying of granite.

In order to control this action and prevent the possibility of further movement, six diamond drill holes were put down around the shaft from the surface to a depth of 500 ft., the purpose being to intercept the rock seams and so to provide them with drainage and thus prevent the accumulation of pressures within the mass of the rock. Observations have been made on the quantity of flow from these holes from the time they were bored to the present. The results are shown in Fig. 23.

It is of interest to observe (*a*) that the reduction in the total leakage has been progressive from year to year; (*b*) that the tendency has been for the leakage to begin a little later and to cease a little earlier each year; and especially (*c*) that the leakage is always greater in winter than in summer.

The greater leakage in winter in this case is due to the same cause which acts to reduce the uplift pressures at the Sherman Island Dam during the colder months, namely, an increase in the size of the channels through which the escaping water passes. The increase in uplift pressures which accompanies a rise of temperature cannot be ascribed to a cause which "* * * not only increases the velocity, but also decreases the loss of head."

HENRY GOLDMARK,* M. AM. SOC. C. E.—In heavy structures, such as the Sherman Island Dam, of which one part is on rock and the adjacent part on a more or less compressible soil, the speaker has found it difficult if not impossible to avoid settlement and cracking. He would like to inquire what means were taken to avoid these difficulties in the Sherman Island Dam.

BYRON E. WHITE,† M. AM. SOC. C. E.—Referring to the curves (Fig. 19‡) showing the hydrostatic heads or pressures in the three test pipes beneath the dam down stream from the sheet-pile cut-off (Fig. 18§), the curves shown by the author in presenting the paper indicate a condition of affairs which is not revealed as satisfactorily by Fig. 19, namely, that the pressure heads in the pipes during 1924 are markedly less than those for the corresponding period in 1923. To be more specific, the maximum pressure head was reduced

* Cons. Engr., New York, N. Y.
† Engr., Utica Gas & Elec. Co., Utica, N. Y.
‡ *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 372.
§ *Loc. cit.*, p. 371.

from about 13 ft. in 1923 to about 11 ft. in 1924, or roughly 15 per cent. This indicates that considerable silting behind the Sherman Island Dam and perhaps beneath it has already taken place.

The curves presented by Mr. Merriman showing progressive decrease in the seepage at one of the shafts of the Catskill Aqueduct probably are representative of the condition to be expected at the Sherman Island Dam. There is, however, one notable difference, namely, that in the case cited by Mr. Merriman the maximum seepage occurred during the cold months, while at Sherman Island the minimum occurs during those months.

Unless some unusual condition arises, it seems fair to conclude that a progressive decrease in pressure will take place as time goes on and, if so, this will confirm the thought that after a period of years, very little, if any, hydrostatic pressure beneath the dam will be shown by the readings taken at these pipes. If such proves to be the case, a knowledge of the facts will do much to justify designing engineers in adopting what now seems a bold design for use in similar difficult situations.

It is hoped that in his closing discussion, the author will bring the curves down to date, including the latest reliable observations, as this will complete two annual cycles of variations, which, if in accord with the speaker's assumption, will further confirm his conclusion. It is also hoped that these observations will be kept up and, at a later time, that they will be made available to the profession as a guide to the design of future structures of this character.

B. F. JAKOBSEN,* M. AM. SOC. C. E. (by letter).†—The multiple-arch section of the Sherman Island Dam founded on sand is decidedly interesting and the problems encountered seem to have been carefully studied. To have constructed a gravity dam of equal safety would have increased the cost possibly 100%, or even more.

Referring to Table 2‡ the writer does not understand whether the arches were built at the same time as the buttresses, or what provisions, if any, were made to permit a re-adjustment of the various parts of the dam without producing internal stresses. Evidently, since the measurements of movements of the multiple-arch dam were made, the author expected such movement.

Referring to Fig. 11,§ and scaling the position of the resultant, it appears that uplift was not taken into account. Also, it would have been instructive to have had some actual tests as to whether or not uplift existed under the gravity section.

It seems to the writer that the solution by means of a multiple-arch dam is very much to be preferred to either a gravity type or a dirt dam, but he believes that perhaps some provision for permitting slight movements of the various parts would have been desirable.

* Cons. Engr., Care, Flood Control, Los Angeles, Calif.

† Received by the Secretary, March 11, 1925.

‡ *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 355.

§ *Loc. cit.* p., 356.

CHARLES W. COMSTOCK,* M. AM. SOC. C. E. (by letter).†—The writer has found Fig. 19‡ which shows the observed relation between water temperature and sub-pressure, to be of particular interest. Those who mentioned this point in the oral discussion, with one exception, explained the phenomenon by reference to the known variation of viscosity of water with temperature, and dismissed it without further comment. At first thought, the same idea occurred to the writer, but further consideration forced the rejection of this explanation as inadequate.

The absolute viscosity of pure water at 0° cent. (32° Fahr.) is 0.017928 dynes per sq. cm., and at 20° cent. (68° Fahr.), it is 0.01006 dynes per sq. cm. For a constant head the velocity of flow through a given capillary tube or network of capillaries is inversely as the absolute viscosity. It would seem, therefore, that the volume of water flowing under the dam in winter should be 56% of that in summer; but it is not clear how the piezometric head can be affected except to the extent of the difference in velocity heads. The velocity of flow in the sand probably does not exceed 8 or 10 ft. per day, so that the effect on the sub-pressure of any change in velocity would not be measurable. To the extent that the sub-pressure is affected by this cause, however, it must be the reverse of that shown in Fig. 19, the pressure being higher in winter when the velocity is less.

It seems much more probable that the observed variation in sub-pressure is due to the change of elevation of the tail-water. Perhaps, if sub-pressure and tail-water elevation were plotted together, they would show the same synchronism as is shown in Fig. 19. The author states:§

"The elevation of the water surface in the pipes varies closely with changes in elevation of the river surface just below the dam, while changes in pond elevation have less relative effect."

The apparent relation between sub-pressure and temperature may be only incidental and due to the fact that the winter season is the period of low tail-water.

The author states that the design considered sub-pressure as acting on the entire base, although the pressure probably acts on less than 50% of the area because of sand contact.

The writer believes that provision for sub-pressure on the entire base, as in this design, is correct—not ultra-conservative. The view that sand contact can protect against sub-pressure is illusory. Pressure on the under side of a sand grain in contact with the structure has the same effect as water pressure directly against the concrete base. If all the sand grains were equal prisms and were arranged so as to form a series of prismatic columns extending from the lower side of the structure to an impermeable rock foundation at any distance below, there might be some excuse for reducing the area subject to upward pressure; but, with the haphazard arrangement of sand grains of all shapes and sizes, approximating much more nearly to a group of packed spheres

* Engr., Dwight P. Robinson & Co., Inc., New York, N. Y.
† Received by the Secretary, March 12, 1925.
‡ *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 372.
§ *Loc. cit.*, p. 371.

than to prisms with vertical axes, any imagined protection against upward pressure by sand contact is too uncertain for use as an element in design. Volume porosity is not a measure of the area subject to pressure. For example, consider a mass of equal spheres with the closest possible packing. The porosity is only 26%, but the entire area of the base of a structure resting on such a mass would be subject to full upward pressure of any fluid filling the pores. It is true that a structure weighing 3 tons per sq. ft. cannot rest on geometrical points; but it can be supported by an actual area of contact of less than 1 sq. in. for each square foot of base.

The experiment described by Mr. Meem, in which he found a greater pressure necessary to raise a piston surrounded by sand than one immersed in water only, is susceptible of an explanation other than that of reduced area of contact. Had Mr. Meem made a number of observations with the piston at various depths in the sand, he might have found the increased pressure accounted for by friction of the sand on the sides of the piston. Further experiments with Mr. Meem's apparatus would be of great interest.

Water-proofing of the face of the dam is of vital importance. The best of concrete is not water-tight and, lacking a water-proof face, will become saturated. The arches are thin (only 2 ft. thick) and are subject on the down-stream side to temperatures below freezing throughout the winter. Thus, the absorbed water will freeze, and the concrete will be subject to a slow but certain and powerful disruptive effect. The writer knows of one important multiple-arch dam in which this action proceeded to the danger point in the course of a few years.

The author says*: "Before the dam was closed, the northern half was given four coats of 'Ferritex' water-proofing." If this material proves effective he has provided against the destructive action mentioned. No statement is made concerning the southern half of the structure. It would be interesting to know whether some other water-proofing process was applied to that part or whether for some reason it was left untreated.

The author makes no reference to calculated stresses in the piers. It would be a matter of interest if he would outline his analysis and give the resulting stresses. The writer has recently examined an important multiple-arch dam in which every pier showed an open crack beginning near the face about the middle of its height and extending approximately perpendicular to the face nearly to the down-stream ends of the piers. These cracks gave every evidence of resulting from excessive tension or shear—perhaps both. In that structure the face of the dam made an angle of about 50° with the horizontal except near the top. The cracks were not due to settlement, for every pier was founded on solid rock. They were probably not temperature cracks, for the climate is equable and freezing is unknown. The conclusion that they are stress cracks seems unescapable.

The report of the Swiss engineer, Stucky, on the Gleno Dam failure in Italy revealed by calculation dangerous shearing stresses in the piers on planes making an angle of about 50° with the vertical, and observations on some of the broken piers showed actual failure along these planes. The danger lines

* *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 354.

calculated and observed by Stucky corresponded closely to the cracks already noted by the writer.

The peculiar profile of the piers in the Sherman Island Dam may result in stresses radically different from those in the more usual type, and for this reason the author's analysis would be all the more welcome.

WALTER H. WHEELER,* M. AM. SOC. C. E. (by letter).†—This paper presents a description of some interesting hydraulic and structural engineering work. The dam is especially interesting because of the foundation conditions and the design and execution of the structures to meet these conditions. Judging by all the evidence submitted it would seem that it may be regarded as safe and substantial as long as no scouring occurs under the dam. It also appears from the data given that the possibility of any such scouring is being reduced each year.

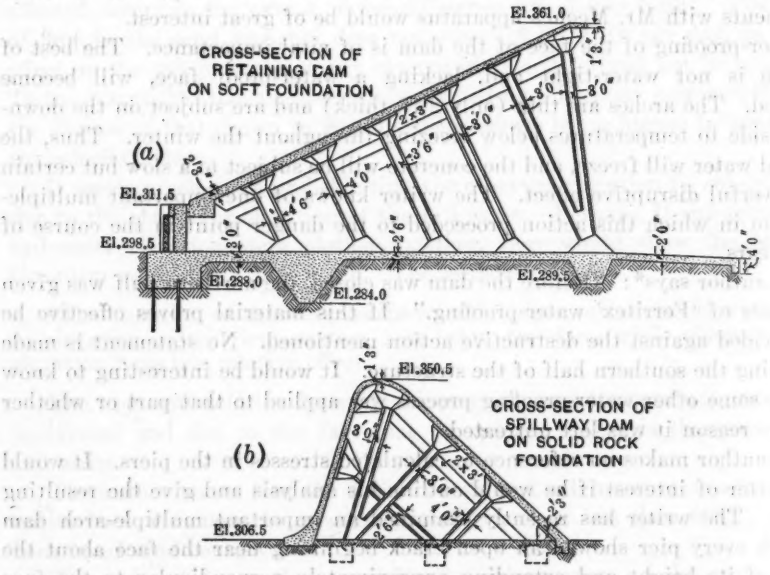

FIG. 24.

The writer is much interested in the design of reinforced concrete dams, and believes that when well designed and constructed they may be regarded as permanent structures, provided maintenance is not too flagrantly neglected. There is sufficient experience with hydraulic structures of reinforced concrete to establish this as a fact. It is the writer's experience, however, that concrete subjected to the action of water and frost offers much better resistance to such action when its fine and coarse aggregates, in addition to all the recognized requirements, are materials which themselves will not be disintegrated by frost, and have been washed clean of all clay and loam.

* Designing and Cons. Engr., Minneapolis, Minn.
† Received by the Secretary, March 23, 1925.

In Fig. 24 (*a*) is shown another type of reinforced concrete design which might have been used for the retaining wall section of the Sherman Island Dam, and which, the writer believes, would have reduced the concrete yardage required in that part of the dam more than 25% without sacrificing the strength, stability, or efficiency of the structure.

Likewise, in Fig. 24(*b*) is given a reinforced concrete design of a similar type for the spillway part of the dam. The deck slab is carried over the downstream face to form the spillway and the floor slab is omitted, as it is not required where rock can be reached for the foundation, since the columns can be supported on footings which are designed to take the thrust and are built into the rock. When the rock is stratified and flat, it is advisable to tie these footings together with a strut at the rock line extending from the heel of the dam to the outermost footing.

The writer believes that this reinforced concrete design for the spillway part of the Sherman Island Dam would require only about 30% of the material for the gravity dam as built. Considering the cost per cubic yard of concrete for the reinforced structure complete to be approximately 2¼ times that for the gravity type, the net saving in cost for the reinforced design, as compared with the gravity type structure, would therefore be between 30 and 35 per cent. If designs similar to those of Fig. 24 had been used for both the retaining wall and spillway sections, the cost of the whole dam might have been reduced as much as 25 per cent. The possibility of so great a reduction in the first cost of a structure would warrant consideration of this method in similar cases. It is based on the principle of a flat slab with column supports.

FINAL REPORT OF THE SPECIAL COMMITTEE ON STRESSES IN STRUCTURAL STEEL

Discussion*

By Messrs. A. N. Talbot, F. E. Schmitt, Anson Marston, and J. R. Worcester.

A. N. Talbot,† Past-President, Am. Soc. C. E.—The speaker hesitates to make these remarks, but there is one feature of the work of the Committee that it seems should have consideration. It has a bearing on the work of the Special Committees of the Society. It is stated in the report that this Committee was appointed at the request of a member of the Society that a committee be appointed to report on whether working stresses in steel buildings should be increased. The Board of Direction considered that suggestion, but instead appointed a committee that was "instructed to limit its activities at the present time to the investigation of the properties of commercial structural steel (both mill and stock material) as bearing on the problem of what working stresses should be allowed for building construction."

The Committee has reported some tests made in 1924 on material said to fill the requirements of the American Society for Testing Materials, but it has not presented data showing in a comprehensive way the quality of the material that goes into buildings. This report gives some very general information on the stresses and properties of materials. Evidently, the Committee does not think that the variation in material that is to be found is worth consideration.

The Committee also was instructed to report to the Board of Direction on the feasibility of conducting extensive measurements of stress distribution in structural work other than in bridges. The Committee now reports that a committee should be appointed to conduct such tests. No information on the feasibility of this work is given. The speaker is not yet convinced that tests of this nature would give information worth the cost and the time, except possibly for some of the details of structural design.

The personal feeling of the speaker is that it would have been very much better if the instructions to the Committee had been followed and the Committee had brought information upon which a change in the value of working stresses could be based.

The speaker feels, as no doubt all do, that the matter of working stresses in steel or other materials should be decided upon the recommendation of men

* Continued from April, 1925, *Proceedings*.

† Prof. of Municipal and San. Eng., and in Chg. of Theoretical and Applied Mechanics, Univ. of Illinois, Urbana, Ill.

who are in the special line of work, who know the difficulties, who know the defects, who know the possibilities of something wrong going on in construction, and of the loads which might come. He has great respect for the engineering ability and judgment of the members of this particular Committee; but the report does not present the information asked for. It would appear that the report of the Committee would obtain better standing in the Engineering and Architectural Professions, and the Society would be given a better standing, if the Committee had followed instructions and had furnished other material than that presented.

F. E. SCHMITT,* M. AM. SOC. C. E.—When the work which resulted in the report submitted was undertaken, the Committee saw a definite task before it. It planned its procedure after appraising this task in the light of the instructions given it by the Board of Direction. These instructions were very fully discussed by the Committee, and were applied by it in the light of the existing situation. It was known that this situation (through a letter from L. D. Rights, M. Am. Soc. C. E.), had been the original incentive for the appointment of the Committee. The situation was believed by the Committee to be urgent and to call for carefully considered action on its part.

Perhaps it is less important, at present, to ask whether or not the Committee misconceived the scope of its instructions than to discuss the facts and conclusions set forth in the report. The report was formulated only after very lengthy discussions in the Committee, as many fundamental differences of view had to be smoothed out and numerous phases of the subject had to be considered in detail. It is fair to say that these included all the matters dealt with in the Minority Report. The conclusions reached are believed to be conservative and sound, and to have a constructive bearing on the present-day problems of steel structural engineering.

It is desirable, however, that these conclusions should be subjected to critical discussion from various points of view. The value of their application in practice depends on how well they meet the requirements of the conditions arising in structural work. It is hoped, therefore, that they may be thoroughly scrutinized and tested in the light of these conditions.

ANSON MARSTON,† M. AM. SOC. C. E.—To succeed Professor Talbot as Chairman of the General Research Committee, in 1924, fell to the lot of the speaker against his quite urgent protests, because he felt that the oversight of a general program of research such as had been undertaken by the Society, should be continued in one man's hands for a considerable period rather than be modified year by year.

It took the speaker about six months to get a fairly clear understanding of the exact situation as to the work of this Committee. He then came to the conclusion that it was best to leave the exact scope of the work of the Committee to the good judgment of its members; and that is still his opinion.

At first the speaker had favored an extensive period of research, in which the Committee should collect much experimental data before making a definite

* Assoc. Editor, *Engineering News-Record*, New York, N. Y.
† Dean, Dept. of Eng., Iowa State Coll., Ames, Iowa.

recommendation as to stresses. During the year he modified that conclusion for which he accepts full responsibility.

J. R. WORCESTER,* M. AM. SOC. C. E. (by letter).†—Without desiring to be hypercritical, the writer is forced by a study of this report to the conclusion that it consists largely of a labored attempt to justify a decrease in the factor of safety heretofore customarily used in the design of structural steel in buildings. No evidence is introduced to show that assumptions for loading have been increased, or that the strength of the steel now in use is greater than that of the material commonly employed when the present unit was adopted. All engineers know that the reverse is true. It is evident, therefore, that the entire question resolves itself into whether they have been wasting material by allowing an unnecessary leeway.

The Committee frankly admits that it "was not able to discover a method of rational calculation" by which it could justify increased working stresses, but seems to rely upon its belief that in "numerous instances of faulty performance * * * no case of failure or unsatisfactory service is chargeable to high working stresses". Just what does this mean? Many failures are known to have occurred, and probably they have been due to over-stress of some part. This over-stress may have been caused by an over-load, by a "neglect of vibration", by "variation of the material", by "uncertainties of analysis", by "imperfections of construction", by "secondary stresses", or by "such effects as may arise from settlement". After an accident it is often possible to determine the cause, but the only insurance against failure from some of these obscure causes lies in using a sufficient margin of safety. Who can tell how many accidents have been avoided by the use of a 16 000-lb. unit, that might have happened if 20% less steel had been used?

The Committee disclaims any intention to provide for a "factor of ignorance" to cover certain elements of the design, but it arbitrarily allows a factor of 50% to cover other elements of ignorance, which are to include "uncertainties of loading, variation of material, uncertainties of analysis and imperfections of construction" and "emergency conditions". The first three of these elements will be further considered.

Uncertainty of loading is something against which no building code, even when enforced by the most efficient building department, can fully guard. Every structural engineer must find cases, now and then, of over-loads exceeding 50% of the designed load. In many instances over-loads of 100%, and even much greater, have been discovered. Such conditions have been found in numerous cities.

As to the variation of material there is no need of going back of the tests of steel columns fabricated under ideal conditions referred to by the Committee,‡ to find one which failed at a stress 11% below the limit fixed by the Committee as a safe assumption, while within the field of tests there was a variation in ultimate strength of 60 per cent.

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* Cons. Engr., Boston, Mass.

† Received by the Secretary, March 10, 1925.

‡ *Transactions*, Am. Soc. C. E., Vol. LXXXIII (1919-20), p. 1583.

For uncertainties of analysis, reference might be had to the investigation of Almon H. Fuller, M. Am. Soc. C. E.,* who found by actual measurements an average stress of 67% more than the calculated stress, and a variation between two edges of a column of 8 200 lb., or 122% of the lesser stress. While the positive statement that "emergency effects cannot all occur simultaneously" would generally be true, exception must be taken to the implication that "all such emergency effects" must occur simultaneously to produce disaster. The possibility of synchronous action of two or more "emergency effects" cannot be ignored. A study of many past failures would probably disclose that, in the majority of cases, not more than two "emergency effects" were operative at the time, and seldom, if ever, more than one. It must also be recognized that one "emergency effect" may produce failure.

The Committee has predicted its conclusions on a quality of steel "meeting the structural steel specification of the American Society for Testing Materials", and yet its argument is based on the use of open-hearth steel. The fact appears to be ignored that there are two specifications of the American Society for Testing Materials, one for bridges and one for buildings, the former requiring open-hearth, and the latter permitting Bessemer, steel. The claim is made that almost no Bessemer steel is now used in structural work, but it is not excluded from the specification for "steel for buildings." The Committee lays stress on the uniformity of the product now in use, and substantiates this by quoting tests which gave yield points varying from 32 000 to 44 000 (37%), with a small percentage falling an unnamed amount below 32 000. This is not a very remarkable uniformity. It is also a striking feature of this argument that all the tests quoted were of material ordered to a specification which limited the yield point to not less than one-half the ultimate, and presumably did not include any which failed to meet the specification.

No reference is made in the report to the effect on structural steel of cold working and straightening. This is a subject which has received considerable study in the past, and which is now being investigated by the U. S. Bureau of Standards. It might, at least, be given a place among the components of the "factor of ignorance".

The report would seem to imply that only high grade designers and erectors were engaged in the construction of buildings. Unfortunately, the number of those deficient in their qualifications for such work emphasizes the necessity for conservative control. Nearly every city has its small caliber steel erector who will take any job from a fire escape to a three or four-story, bolted beam and column structure. Frequently, he makes his assembly from job lots of steel, in the purchase of which the price is the main consideration. "Cut-up stock" is often used, and although this may not imply that the material is sub-standard in grade, it surely is no guaranty of quality.

In the concluding numbered paragraphs of the "Summary and Recommended Stresses",† lies the meat of the report. They should have been printed in italics or otherwise been given more prominence. These paragraphs include

* *Bulletin 71*, Eng. Experiment Station, Iowa State Coll.; abstracted in *Engineering News-Record*, October 2, 1924, p. 540.

† *Proceedings*, Am. Soc. C. E., March, 1925, Papers and Discussions, p. 403.

conditions which practically nullify all the previous recommendations, as they impose requirements which almost never will be fulfilled in building construction work. What they state in substance is that, if the need of a factor of safety can be eliminated, higher stresses may be allowed. It would have been well to add another paragraph to the effect that "considering the impossibility of enforcing these conditions, it would be unsafe to adopt the units herein recommended; they have no application in ordinary building construction practice".

THE INFLUENCE OF THE AUTOMOBILE ON REGIONAL TRANSPORTATION PLANNING

Discussion*

By Stephen Child, M. Am. Soc. C. E.

Stephen Child,† M. Am. Soc. C. E.—Landscape architects, while basing their work on scientific data, make every effort to keep art and beauty constantly in mind. They maintain that the useful and the beautiful are the two blades of a pair of scissors—that both are equally essential to good work. Too often the engineer has striven to do with one blade what would have been better done with two and has thereby produced a botched job. To illustrate, for ten years the speaker was assistant City Engineer of Newton, Mass., and during that time an important boulevard system was laid out extending across the city from the Boston line to the Charles River. This Commonwealth Extension has two roadways and a grassed, tree-shaded, central strip reserved for the trolley car lines.

When it came to the planting of the trees, only one blade of the pair of scissors was used, for several miles of that central parking space were planted with a double row of Rock Maples. These, as they grew up, assumed an oval outline, with the result that an ugly gash had to be made in every tree to permit the trolley car to pass. The central trolley section should have been planted with elm trees or any others that would naturally arch over the strip without necessitating their mutilation. The point to be emphasized is that unless the beauty as well as the convenience of the community receives attention bad city planning will result.

The writer heartily agrees with the author in his suggestions as to decentralization and helping to promote the establishment of satellite towns. There is one suggestion that may be criticized—Mr. Damon recommends having a radius of the property line at street corners of 15 ft. and the radius of the curve of the curb line as great as 30 ft., and yet he speaks feelingly of managing traffic to help pedestrians. In the arrangement suggested, a pedestrian must go around that 15-ft. turn and cross the paving where it is narrowest. He ought not to blunder ahead and cross in the middle of the curve where he would be meeting the traffic at an acute angle. One of the fundamental principles of controlling traffic is to arrange it so the streams cross at right angles. A 15-ft. radius for curves at property lines and a 30-ft. radius for the curves at the curb line is too generous an allowance. It makes the pedestrian either take extra steps or extra risks.

In the business center of Los Angeles, Calif., there are the north and south streets—Spring Street, Main Street, Broadway, and others—crossed at right

* This discussion (of the paper by George A. Damon, Esq., presented at the meeting of the City Planning Division, Pasadena, Calif., June 19, 1924, and published in April, 1925, *Proceedings*), is printed in *Proceedings* in order that the views expressed may be brought before all members for further discussion.

† Landscape Archt.-Consultant in City Planning, San Francisco, Calif.

angles by east and west streets—Fifth Street, Sixth Street, and others. Until a better solution can be evolved, the speaker's suggestion is that the traffic be restricted in alternate streets of this super-congested district, Main Street, for example, to one direction only and Spring Street to the other direction and likewise with Fifth and Sixth Streets. Would not this reduce congestion at the corners about one-half? This is not put forward as the best or a permanent solution, but as something to be tried as a temporary measure.

In Palo Alto, there is now a complicated transportation problem with the two factors of auto busses and trolley cars, much in evidence in the discussions. The main line of the Southern Pacific Railroad runs practically north and south, dividing the town into two main parts—on the east side, the village with about 7 000 population and on the west side, nearly a mile away, Stanford University, with a population of approximately 3 000.

At present, the Peninsula Street Railroad has a double-track line running west from the station on University Avenue—the main street—for about ½ mile, where the tracks branch, one running south for about 1 mile and another continuing straight on in University Avenue for 1 mile or more. From the Railroad Station on the ½ mile of double track there is 10-min. service, which is Mr. Damon's limit for effective trolley car service. He claims that for a service of 15 or 20-min. interval, motor busses are more efficient. On the single-track streets, the cars run on 15-min. intervals.

The problem is complicated by the fact that University Avenue needs paving badly. The Street Railroad Company has refused to pay its share of this repaving, taking the ground that it cannot afford it; it has actually gone before the Railroad Commission and asserted that it would rather give up its franchise than do it. The speaker is informed that a similar state of affairs exists in several other towns. The problem is, would it be better to abolish these unprofitable street railways and have auto busses?

The introduction of this kind of service has a bearing on another factor—the grade-crossing problem. As to this, perhaps the only feasible proposition is to raise the railroad tracks 3 or 4 ft. and depress University Avenue enough to pass under them. If the trolley lines are maintained, there must be a subway broad enough to accommodate at least three lines of traffic, one for the trolley and one each way for other traffic. If, however, the trolley is abolished, there would be need for a width that would accommodate only two lines of traffic, the auto busses could use these lines as well as other vehicles.

There is another complication, however, Stanford University, nearly a mile west of the railroad, depends on the railroad for freight accommodations for many kind of supplies, oil, coal, etc. The University has an agreement with the Trolley Company and the Railroad Company whereby, at convenient hours, freight and tank cars are moved over the trolley track to the University buildings and the University authorities are very urgent that this arrangement be maintained.

No solution for the problem has yet been determined, but these details are mentioned to show how complicated such a matter may be even in a small town and how difficult it is to solve it on general principles, even such as are so clearly laid down by Mr. Damon.

IMHOFF TANKS—REASONS FOR DIFFERENCES IN BEHAVIOR

Discussion*

By Harrison P. Eddy, M. Am. Soc. C. E.†

Harrison P. Eddy,‡ M. Am. Soc. C. E. (by letter).§—The writer is gratified by the valuable discussion which has been brought out by the comparison of the essential conditions affecting the behavior of Imhoff tanks.

Mr. Hammond's suggestion,‖ that it would be wise to instruct the operator to determine the capacity of the tanks under his care and operate them according to the capacity found by test, is excellent advice. Usually, however, the operator has to run the tanks according to the load delivered to the plant and although experience might indicate that the tanks were of insufficient capacity, he must operate them under the overload, or by-pass the sewage. The by-passing of sewage is, of course, a procedure which cannot be done in all cases.

Mr. Hammond's theorem that "the tank having the greatest ratio of depth to capacity would give the most successful performance" seems to be just the converse of that indicated by experience. According to his theorem the tanks at Plainfield, N. J., should function more satisfactorily than those at Fitchburg, Mass., the ratios of depths to cubic foot capacity per capita being 13.25 and 13.12, respectively.

Experience seems to indicate that, all other conditions being identical, the following theorem may more nearly approximate the facts: "The tank having the greatest ratio of depth to number of persons served per cubic foot of sludge compartment capacity will function the most successfully." If this theorem is correct, it should follow that a certain ratio will give satisfactory results for the several depths, at least within limited ranges. The application of this theorem to tanks 10, 20, and 30 ft. deep, on the assumption that 40 is the optimum ratio, gives the results shown in Table 22.

The tendency indicated by Table 22 appears to be borne out by experience, although it should be noted that this theorem means simply that, other conditions being the same, sludge compartment capacity expressed in persons served per cubic foot is directly proportional to depth.

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* Discussion of the paper by Harrison P. Eddy, M. Am. Soc. C. E., continued from November, 1924, *Proceedings*.

† Author's closure.

‡ Cons. Engr. (Metcalf & Eddy), Boston, Mass.

§ Received by the Secretary, April 18, 1925.

‖ *Proceedings*, Am. Soc. C. E., August, 1924, p. 901.

TABLE 22.

Depth of tanks, in feet.	Optimum ratio of depth to number of persons per cubic foot capacity.	Sludge Compartment Capacity.	
		Persons per cubic foot.	Cubic feet per capita.
10	40	0.25	4
20	40	0.50	2
30	40	0.75	1.33

The depth of Imhoff tanks appears to have relatively little effect on temperature conditions in the digestion compartment, as this temperature follows very closely the temperatures of the sewage delivered to the tanks. The temperature changes which take place in the sedimentation compartment and in the sludge digestion compartment are not particularly rapid in either. Although the temperatures of the sewage and sludge in a shallow tank would tend to respond somewhat more quickly to changes in atmospheric temperature, the actual temperature change in sewage and sludge would be relatively small and unimportant. It is quite likely that daily changes in barometric pressure are of more immediate effect on foaming or the rising of gas-lifted sludge than daily changes in temperature.

For the sake of accuracy, it should be stated that free interconnection of sludge digestion compartments has been put into effect in only one of the nine tanks at Schenectady, N. Y. In this one tank the original openings in the partition walls were simply extended to the bottom of the tank, the net effect of the changes resulting in far less ease of intercommunication than in the case of the plants at Fitchburg or Rochester, N. Y. Lime has not been used at Schenectady for several years.

Such foaming as has occurred at Fitchburg in the period of ten years since operation of the plant started has been inconsequential in amount compared with foaming difficulties in Plainfield or Schenectady.

The greater proportion of mineral matter present in the bottom sludge as drawn than in the suspended solids of the sewage or in the scum is explained by Mr. Skinner* as being due to the concentration of particles of mineral matter in the bottom of the tank. Another reason is the actual gasification and liquefaction of the organic portion of the sludge particles which, in the older and deeper lying sludge, will have proceeded to a greater extent than in the upper and more recently deposited sludge.

The arrangement of the tanks at Schenectady with eight practically separate sludge compartments in a line results in a tendency for the end compartments to become overloaded, although unsatisfactory conditions with respect to foaming and rising scum have occurred in the central as well as in the end compartments.

The writer does not feel that the hopper bottom has any advantage over the trough bottom, providing the sludge draw-off pipes are equally distant from each other in both cases. In fact, under some conditions, there may

* *Proceedings*, Am. Soc. C. E., August, 1924, p. 905.

be an advantage in the trough bottom. A large proportion of the bottom provided with hoppers is filled with the mass of masonry between the apices of adjoining hoppers. In trough bottoms this space may be occupied with mineral or other inert matter deposited from the sewage, but there does not appear to be any reason why the volume of such deposit should be greater than that of the masonry of the hopper bottom. In the absence of considerable grit the space thus occupied may be much less than that occupied by the masonry. Sludge will flow practically as well over the deposits as over the concrete hoppers. With trough bottoms, sludge draw-off pipes may be placed at shorter intervals, if desired, than in the case of hopper bottoms, thus making available space which otherwise would be occupied by deposits in the case of troughs or by masonry in the case of hoppers.

The writer is not sure that tall narrow gas vents are other than a secondary factor in the foaming phenomena. Foaming appears to be connected with a very rapid formation of gas, a biological condition which must be due primarily to factors affecting micro-organic activity. It is conceivable that where such rapid formation of gas is produced, the tall vents may result in the lifting of the volume of liquid in the gas vents similar to the raising of water by air lifts, as suggested by Mr. Skinner, although it is not quite clear from his discussion how the sealing of the slot by the rising sludge will produce a condition favorable to foaming from the standpoint of air lift.

The writer is unable to agree with Mr. Skinner's method for computing the capacity of sludge digestion compartments. While this method takes into account certain variables it does not give any weight to the effect of depth of tank which the writer believes to be important. Thus, by Mr. Skinner's method, the computed volume of sludge compartment capacity would be the same for a tank 10 ft. deep as for one 30 ft. deep. This does not seem logical when conditions within the sludge compartment are taken into account. A rational method would be to base the volume on an estimate of the density of sludge which appears to vary with the depth of the tank.

It is possible, of course, to compute the capacity of any sludge compartment in terms of cubic feet per capita, but as a means of computing the required capacity the writer does not think it is safe to provide as uniform a number of cubic feet per capita in all cases. Such a uniform allowance, however, may be made where all conditions except tributary population are identical.

Dr. Imhoff's rule of 1.2 cu. ft. capacity for sewage from separate sewers cannot be applied equally well to tanks in the South and in the North and to compartments receiving 50% and 75%, respectively, of the suspended solids of the sewage. Neither does the writer think that the same arbitrary capacity per capita can be applied to tanks of, say, 15 ft. depth and 30 ft. depth.

The formula presented by Mr. Skinner takes into account several of the variables; special allowances for others can be made, or the suggested factor of safety can be applied to cover them. In this formula, he has assumed a sludge containing 90% of water in the tank and has allowed 25% reduction for the combined effect of concentration and digestion. The density of the sludge, as already pointed out, will vary with the depth. Sludge containing

approximately 85% moisture has frequently been drawn at Fitchburg; the average digestion during the year approximates 30 per cent. The allowances for density of sludge and for the digestion accomplished must be based on the design of the tank (depth being the major controlling factor), on temperatures, and on the composition of the sewage.

The aids to proper functioning suggested by Mr. Skinner are excellent, although there is some question in the writer's mind as to the necessity for wide gas vents.

Mr. Downes* has directed attention to the importance of adequate provision for sludge dewatering facilities so that the sludge may be drawn from the tanks as soon as it is ready. A moment's consideration is sufficient to demonstrate that it is uneconomical to delay the efficient functioning of tanks because of inadequate sludge dewatering facilities. The cost of the latter is much less than that of tanks.

The use of alum for conditioning sludge of poor quality appears to have been a valuable aid in the case of the Plainfield plant, but similar satisfactory results have not been obtained at Schenectady.

It should be pointed out that the writer, in computing Tables 7† and 8‡, was basing his computations on purely arbitrary assumptions and the tables were set up for illustrative purposes only. As a matter of fact, deep tanks may be expected to contain sludge which will reach a density of 15% of the solids at the bottom. At Plainfield and Schenectady, however, with shallow tanks, it is not to be expected that sludges of such density can be obtained.

Mr. Downes' explanation and illustration of the gas action in the Fitchburg and Plainfield tanks is interesting and has much merit. In the deeper tanks there is not only a greater accumulation of sludge in the hoppers per unit area of sludge surface, and, consequently, a greater number of sludge bubbles given off per unit of area, but in the deeper tanks there is a greater compression of the gases. It is likely that the larger number and greater expansion of rising gas bubbles in the deeper tanks play an important part in the agitation of the liquid and sludge, thereby assisting favorable digestion processes in the digestion and scum compartments. Furthermore, due to the greater pressure of water in the bottom of deep tanks where gas is being produced, the gases do not acquire sufficient volume to lift the sludge particles, until opportunity has been given for material digestion of the sludge. This digestion renders the particles and the mass of sludge more easily disrupted by the explosive force of the expanding gases as the sludge with the entrained gases rises toward the surface. Due to this disruption, the particles of solid matter freed from gas sink back to the bottom of the tank instead of rising to the surface in the form of floating scum or foam.

The writer is not sure that Imhoff tanks which require for the breaking up of scum in the gas vents more labor than may be necessary at other plants, or the use of mechanical agitators, are unsatisfactory installations. If such

* *Proceedings*, Am. Soc. C. E., August, 1924, p. 914.
† *Loc. cit.*, May, 1924, p. 628.
‡ *Loc. cit.*, p. 630.

measures are successful in producing satisfactory digested sludge, their use is justified, provided the costs are not unduly high.

Unquestionably the slot must be placed sufficiently high to permit the accumulation of sludge in quantities estimated to occur in the time interval required for satisfactory digestion, the controlling time being that of the winter months of low temperature when digestion proceeds at a slow rate. It seems desirable to have in addition a substantial vertical distance to give a margin of safety, the so-called "neutral zone", on which the sludge accumulations will not encroach.

Mr. Downes is correct in his statement that the percentage of solids is not sufficient to express the true relation of solids content to volume of sludge. Specific gravity also is required to give the correct relation. For general purposes, however, as far as the sludge lying in the tank is concerned, it is probably within the limits of error to consider that the volume of sludge per pound of dry solids content varies in inverse proportion to the percentage of solids. It is evident, of course, that the specific gravity of the sludge lying in the tanks must be greater than 1.0 and that the dissolved gases in the sludge have little effect on its specific gravity, except when the pressure of the supernatant liquid is released or reduced. Free gas bubbles reduce the specific gravity of the sludge to 1.0 or less, and in the latter case the sludge rises as scum or foam. When it comes to that portion of the sludge which has become well digested and is drawn from the tanks, or to dewatered sludge lying on sludge beds, the same relation does not hold true due to the interfering effect of voids resulting from expansion of gases and to the effect of changes in character of the solids comprising the sludge.

The drawing of sludge as early in the year as inoffensive sludge can be obtained is an excellent practice as emphasized by Mr. Hartwell.* This course of action provides the maximum space in the digestion compartment during the summer period of intense activity and gas production, when foaming is most likely to occur.

The troubles from oil and grease in Imhoff tanks, referred to by Mr. Cohn,† have been experienced at various other plants. In the design for the new sewage treatment works at Akron, Ohio, provision has been made for a grease-skimming tank preceding the Imhoff tanks for the interception of such grease and oil. It does not seem probable that variations in the quantity of soap curd in different sewages play more than a minor part in the functioning of Imhoff tanks. The spent mash from the illicit manufacture of home brew may tend to produce a large amount of scum difficult to handle, in which biological action is mainly fermentation with the production of carbon dioxide. With excessive production of carbon dioxide, there may actually occur an inhibition of the other biological activities which produce proper digestion, as indicated by the production of methane.

The hydrogen-ion concentration results thus far obtained at Schenectady appear to offer little in the way of explanation for the conditions found to prevail there. The temperature records show that, as previously pointed out

* *Proceedings*, Am. Soc. C. E., August, 1924, p. 923.
† *Loc. cit.*, September, 1924, p. 1132.

by the writer, the sludge compartment has approximately the same temperatures as the sewage and tank effluent.

If the use of mechanical agitators, as described by Mr. Learned,* permit the reduction of the required capacity of sludge digestion compartments from 2 cu. ft. or more per capita to 0.57 cu. ft., or 1.0 cu. ft. per capita, as at Newton, Kans., and Enid, Okla., respectively, such equipment might well be a desirable feature. The costs for such equipment and its operation do not appear to be excessive, although complete data in this connection are not given by Mr. Learned.

Under identical conditions the tank that will function properly without resort to the breaking up of the scum in the gas vents by hosing or other laborious methods and without mechanical agitation, is more satisfactory than the tank which requires this excessive labor or mechanical devices. If by skillful design proper functioning can be secured this should be done.

It is interesting that the rise of the sludge in the plant at Broken Bow Okla., occurred at approximately the same season in the spring as the semi-annual overturn in water reservoirs. In both cases, changes in specific gravity in the top and bottom layers are responsible. In the case of water reservoirs the change in specific gravity is due directly to differences in temperature between the bottom and top layers, whereas in the case of Imhoff tanks the action of the temperature is to stimulate biological activity and the production of gas, thereby producing sludge of specific gravity less than that of water.

Dr. Imhoff's diagram (Fig. 14)† comparing the evolution of gas from sludge at Essen, Germany, in 1924, with that at Worcester, Mass., in 1902, shows comparatively close agreement.

American data substantiate Dr. Imhoff's statement to the effect that the temperatures in the sludge digestion compartment of Imhoff tanks follow those of the sewage. There are, however, no American data, as far as the writer knows, to show the temperature of sludge in separate digestion tanks.

The difference between temperature in separate sludge digestion tanks and in Imhoff tanks depends on climatic conditions and tank construction. The covering of separate sludge digestion tanks would tend toward as high temperature in separate digestion tanks as in Imhoff tanks. There is no justification to assume without qualification that separate sludge digestion tanks will have a much lower temperature than Imhoff tanks.

The cover and gas-trap for the vents of two-story tanks as used by Dr. Imhoff in Germany are of much interest. It is not quite clear how the gases can escape through the cracks of the wood and at the same time persist below the cover to such an extent as to prevent the sludge rising to the under side of the wooden cover. It would appear possible for grease and sludge particles to clog the cracks in the wooden cover and to seal the vent completely, unless a cushion of gas were present below the cover.

Dr. Imhoff's suggestion for constructing separate sludge digestion tanks to provide additional digestion capacity at those installations of Imhoff tanks where experience has shown such capacity to be inadequate, points the way for remedying conditions where other methods fail.

* *Proceedings*, Am. Soc. C. E., November, 1924, p. 1500.
† *Loc. cit.*, p. 1506.

MEMOIRS OF DECEASED MEMBERS

NOTE.—Memoirs will be reproduced in the volumes of *Transactions*. Any information which will amplify the records as here printed, or correct any errors, should be forwarded to the Secretary prior to the final publication.

CHARLES EDWIN COLLINS, M. Am. Soc. C. E.*

DIED JANUARY 8, 1925.

Charles Edwin Collins, the son of Michael and Mary (Cushing) Collins, was born in Roxbury, Vt., on February 23, 1867. In 1870 his parents moved to Northfield, Vt. and he prepared for college in the public schools of that town. In 1886, he entered Norwich University at Northfield, from which he was graduated in 1890 with the degree of Bachelor of Science in Civil Engineering. While at Norwich, he was Corporal, Sergeant, and First Lieutenant and Adjutant in the Corps of Cadets, and a member of the Alpha Sigma Pi Fraternity. He received the degree of Civil Engineer in 1892.

Following his graduation, from 1890 to 1892, Mr. Collins was Assistant Engineer to the late James B. Francis, Past-President, Am. Soc. C. E., for the Locks and Canal Company at Lowell, Mass., and from 1892 to 1895, Principal Assistant Engineer for Pittsfield, Mass., in charge of extending water mains, of constructing reservoirs, surface drainage, sewers, and street pavements, and of surveys. From April to August, 1895, he served as Chief of Party on the construction of a sanitary sewerage system for Malden, Mass., and from 1895 to 1896, as Assistant Engineer in charge of the construction of Payson Park Reservoir for the City of Cambridge, Mass. In May, 1896, he was appointed City Engineer and Superintendent of Water-Works at St. Albans, Vt., which position he retained until March, 1897, when he was engaged as Assistant Engineer on the construction of overhead bridges on the Boston and Albany Railroad. In July, 1897, Mr. Collins became Assistant Engineer for the late Frank L. Fuller, M. Am. Soc. C. E., Consulting Engineer, of Boston, Mass., on the construction of sewers and water-works. In October, 1898, he entered the employ of William F. Shunk as Assistant Engineer in charge of surveys and the location of a railroad between Guayaquil and Quito, Ecuador, where he remained until May, 1899, at which time he was appointed Assistant Engineer with the late W. C. Johnson, M. Am. Soc. C. E., on the preparation of plans for a 10 500 h.p., hydro-electric power plant at Niagara Falls, N. Y. From May, 1900, to May, 1901, Mr. Collins was engaged with Alexander Potter, Assoc. M. Am. Soc. C. E., as Engineer in charge of the construction of sewerage and water-works systems, and from May, 1901, to July, 1903, as a member of Collins Brothers, Consulting Engineers, Philadelphia, Pa. During this time he designed and supervised the construction of several water and sewerage systems, power plants, etc.

From July, 1903, to his death on January 8, 1925, at Athens, W. Va., Mr. Collins was actively engaged as a Consulting Engineer on sanitary and hydraulic work, with offices in Philadelphia. During this time, he con-

* Memoir prepared by John L. Collins, Esq., New York, N. Y.

structed sewerage systems and sewage disposal plants at Lake Placid, Dolgeville, Granville, Malone, and Ticonderoga, N. Y.; Bedford, Pottstown, and Danville, Pa.; Shelbyville, Mt. Sterling, Versailles, and Winchester, Ky.; Morristown, Tenn.; and Moundsville and Weston, W. Va.; as well as waterworks at Milton, Del., and Bridgeton, N. J. The reinforced concrete reservoir at Bridgeton, when completed, was the largest of its kind in the United States. Mr. Collins had also constructed water supply and pumping plants at Lake Placid and Ticonderoga, N. Y., and at Versailles, Ky., and electric light and power plants at Malone, Chateaugay, and Schaghticoke, N. Y.

For five years he had also served as Consulting Engineer for the State Board of Control for West Virginia.

Mr. Collins was a member of the Chestnut Street Baptist Church, Philadelphia, Pa., and of DeWitt Clinton Lodge, A. F. and A. M. of Northfield, Vt. He was also a member of the Engineers Society of Pennsylvania.

He was married on October 8, 1901, to Mabel May Tuggey, of Pittsfield, Mass., who, with two sisters, Dr. Emma H. Collins and Dr. Alice L. Collins, both of Philadelphia, and two brothers, J. Henry Collins, of Lowell, Mass., and John L. Collins, of New York, N. Y., survives him.

Mr. Collins was elected an Associate Member of the American Society of Civil Engineers on March 2, 1904, and a Member on September 13, 1913.

JOSEPH HOFMAN, M. Am. Soc. C. E.*

DIED APRIL 8, 1924.

Joseph Hofman was born in Detroit, Mich., on April 28, 1869. His parents moved to Toledo, Ohio, in 1870, where his father, Samuel Hofman, became a member of the firm of Black and Hofman, later known as The Alexander Black Cloak Company.

Joseph Hofman received his education in the public schools and High Schools of Toledo. His first engineering work was as a Rodman and Draftsman in the County Surveyor's Office in 1884. He continued in this capacity until November, 1886, when he joined the Engineering Corps of the Toledo, St. Louis and Kansas City Railroad ("Nickel Plate Road"). He assisted in the spectacular task of widening, in one day, the 237 miles of track between Toledo and Frankfort, Ind.

In 1890, Mr. Hofman returned to the County Surveyor's Office as Assistant, remaining until 1892. In 1893, when he was only 23 years of age, he was elected County Surveyor, and served until 1898.

From 1898 until 1900, Mr. Hofman was Assistant City Engineer of Toledo, in charge of street paving. During 1901 and 1902, he worked on various surveys, including those for the proposed water supply system for Toledo, and for the proposed cross-town railroad connecting the Wabash and the Wheeling and Lake Erie Railroads through Toledo. He served as Assistant City Engineer until 1905, when he was re-elected County Surveyor, serving until 1909.

* Memoir prepared by George N. Schoonmaker, Assoc. M. Am. Soc. C. E.

Subsequently, Mr. Hofman was engaged, until his death, in private civil engineering work. He specialized in city and suburban surveys and developments, and platted many of the best known sub-divisions of the City of Toledo.

One of his many important accomplishments was that of bringing about the re-establishment of the Ohio and Michigan State Line; this was done in 1915, through his efforts personally and as Chairman of the Legislative Committee of the Toledo Society of Engineers.

Mr. Hofman was unmarried. He is survived by a brother, Mr. A. L. Hofman, and a sister, Mrs. Ella Freeland, both of Toledo. His death occurred at Toledo on April 8, 1924.

He was a Past-President of the Toledo Chapter, American Association of Engineers; a member of the Toledo Rotary Club, Toledo Chamber of Commerce, Toledo Lodge No. 53 B. P. O. E., Knights of Pythias, B'nai Br'th, and Rubicon Lodge, Collingwood Chapter, and Grafton M. Acklin Council, A. F. and A. M.

Mr. Hofman was elected a Member of the American Society of Civil Engineers on August 9, 1920.

HORACE LOOMIS, M. Am. Soc. C. E.*

DIED MARCH 8, 1925.

Horace Loomis was born in Binghamton, N. Y., on July 14, 1840. He received his early education in private schools and Binghamton Academy. In 1860, he was graduated from the State Normal School at Albany, N. Y. (now known as Teachers' College), and served for two years as a Tutor in Mathematics in the Albany Academy. He was graduated in 1865 from Rensselaer Polytechnic Institute, Troy, N. Y., with the degree of Civil Engineer.

For the next ten years Mr. Loomis practiced his profession, devoting most of that time to railroad work. During this period, he served as an Assistant Engineer with the Lehigh Valley Railroad Company, the Lehigh Coal and Navigation Company, the Erie Railroad Company, and several other railroad companies.

He went to Mount Vernon, N. Y., in 1869 as Chief Engineer under the Commission appointed to improve the old White Plains Road between Mount Vernon and White Plains, N. Y., and several contributory roads. In this position he supervised the extension and rebuilding of many streets and highways.

In 1875, Mr. Loomis entered the employ of the City of New York as Assistant Engineer in the Department of Water Supply, and among other things made surveys for the New Aqueduct from Croton Lake to New York. He also made a survey of the Housatonic River for an additional water supply and did similar work in connection with the Bronx River.

* Memoir prepared by Charles Warren Hunt, Secretary Emeritus, Am. Soc. C. E.

In 1880, he became Chief Engineer of Sewers of New York City and, with the exception of a brief tenure of the office of Commissioner of Street Cleaning in 1890, served in that capacity until 1914, when he was placed on the retired list, incidentally being the first Municipal Engineer to receive a pension.

Mr. Loomis found time notwithstanding his engrossing professional engagements to participate actively in civic and business affairs. He was President of the old Village of West Mount Vernon for two years, just previous to its consolidation with Mount Vernon. He served for two years as Trustee of the Village of Mount Vernon, as Town Auditor, and was elected Excise Commissioner, but did not serve his term. He was President for eleven years of the Peoples Bank of Mount Vernon, which was later incorporated as the First National Bank of Mount Vernon. He also served for more than a year as President of the Mount Vernon National Bank.

He was a member of the Municipal Engineers of New York, the Engineers' Club of New York, the Alumni Association of the State College of Teachers, the Alumni Association of Rensselaer Polytechnic Institute, and the Men's Club of Trinity Protestant Episcopal Church of Mount Vernon.

It seems almost unnecessary, in view of the above record, to call attention to the fact that notwithstanding his noteworthy professional achievements and technical ability, he had those rare broad and sterling human qualities which made him a factor in the political, business and social activities of the city in which he lived for more than half a century.

Mr. Loomis is survived by two sons, Horace Benjamin Loomis, of New York, and Romeo F. C. Loomis, of Mountainberg, Ark.; and four daughters, Miss Harriet J. Loomis, of Mount Vernon; Mrs. Anne V. Stubbings, of Bernardsville, N. J.; Mrs. Mary Alice Sellars, of Kaycee, Wyo.; and Mrs. Emma L. Bishop, of Garden City, Long Island; and by two sisters, Miss Eleanor Loomis, of Binghamton, N. Y., and Mrs. George W. Robinson, of New York.

Mr. Loomis was elected a Member of the American Society of Civil Engineers on November 5, 1879, and served as a Director of the Society from 1910 to 1912 and as Vice-President in 1912.

BERTRAND CLIFFORD MARTIN, Assoc. M. Am. Soc. C. E.*

DIED JUNE 8, 1924.

Bertrand Clifford Martin, the son of Nelson H. and Estelle G. Martin, was born at Fort Fairfield, Me., on November 18, 1879. He was graduated from the University of Maine, at Orono, in 1901, with the degree of B. C. E., his father having been graduated from the same college. During his college days, Mr. Martin was a fine athlete and for two years was a pitcher on the University baseball team.

* Memoir compiled from information on file at the Headquarters of the Society.

In September, 1901, he joined the staff of the Bangor and Aroostook Railroad Company, as Levelman on the survey of the Fish River Railroad. He remained with this Company until 1903, serving at different times as Transitman and Assistant Engineer in charge of seven miles of railroad construction at Portage, Me., and of a four-mile branch line of the Bangor and Aroostook Railroad at Van Buren, Me., which included the construction of an 800-ft. timber trestle on a pile foundation.

From June, 1903, until November, 1906, he was employed by Westinghouse, Church, Kerr, and Company, of New York, N. Y., first as Instrumentman on railroad location in the western part of Virginia, and, subsequently, on the location and construction of foundations for steel poles of the high-tension line on the electrification of the Long Island Railroad.

On the completion of the project in July, 1905, Mr. Martin was sent to Ohio where he was employed on railroad work, in charge of a party, locating twenty miles of the double-track interurban electric line between Vanport, Pa., and Wellsville, Ohio. He returned to the New York Office of the Company in March, 1906, and drew plans of track layouts for the railroad terminal at Toronto, Ont., Canada, and checked the track layout for the Pennsylvania Terminal in New York.

Mr. Martin accepted the position of Assistant Engineer in the office of the Designing Engineer with the New York Central and Hudson River Railroad Company, in November, 1906, where he was engaged in designing and estimating the cost of track work, passenger and freight yard layouts, masonry, water tanks, structures, etc. He displayed such marked ability in this position that he was placed in charge of the Resident Office, at Watertown, N. Y., in 1909, afterward being transferred to Utica, N. Y., in a similar capacity.

From 1913 to 1916, Mr. Martin was Engineer in charge of the four-tracking of the Hudson Division of the New York Central and Hudson River Railroad Company, with headquarters at Poughkeepsie, N. Y., and from 1916 to 1920, he handled the preliminary surveys, location, etc., on the Hudson River Connecting Railroad, leaving the work in excellent condition for construction. He was also in charge of the Mohawk and St. Lawrence Divisions of that railroad.

After the World War, when the Government faced the task of returning the railroads to their owners, Mr. Martin was transferred to the New York Office of the Company where he was placed in charge of a re-valuation of the railroad properties. On the completion of this work, he returned to his position as Resident Engineer on the Hudson River Connecting Railroad with headquarters at the Divisional Office at Albany, N. Y.

Owing to his familiarity with construction details, and following a lapse in field activities, he was placed in charge of roadway completion reports, continuing in this position until the authorization of the construction of the Hudson River Connecting Railroad in 1922. Mr. Martin was then made Resident Engineer in charge of the Castleton Bridge, spanning the Hudson River and carrying the Hudson River Connecting Railroad into Selkirk Yard, including connections with the Boston and Albany Railroad and the Hudson Division of the New York Central Railroad, and held this position at the time

of his death which occurred on June 8, 1924, as a result of pneumonia that developed after a short illness. He is survived by his wife, Adelaide W. Martin, two sons, George Nelson and Charles Bertrand Martin, his mother, and a brother, Charles H. Martin.

Mr. Martin was competent and faithful in his work and always gave of his best to his employers by whom he was held in high esteem. He was of a cheerful disposition, interested chiefly in outdoor sports, his home, and his work.

He was a Mason, a Member of the American Railway Engineering Association, and of the Columbia County Country Club, where he found recreation in golf and tennis. He was also a member of the Dutch Reformed Church.

Mr. Martin was elected an Associate Member of the American Society of Civil Engineers on May 4, 1909.

JACOB STEPHEN SPIKER, M. Am. Soc. C. E.*

DIED APRIL 28, 1924.

Jacob Stephen Spiker, the son of John and Jane Spiker, was born in Clay County, Illinois, on June 5, 1861. He received his early education in the public schools of Clay County. After teaching for two years, he entered Vincennes University from which he was graduated in 1887.

On leaving the University, he was elected County Surveyor of Knox County, Indiana, and filled this office for three years, resigning to pursue further studies. Accordingly he entered Purdue University and took a special course in civil engineering, which he completed in 1893.

Returning to Vincennes, Ind., Mr. Spiker opened an office and engaged in private practice. He was also appointed Engineer of Bridges and Roads for Knox County, Indiana.

In 1897, he was elected City Engineer of Mt. Carmel, Ill., and designed and constructed street paving, sewers, and water-works. In the following year he was made Chief Engineer of Gills and Shaker Prairie Levee Districts in Sullivan and Knox Counties, Indiana, involving the design and construction of about 80 miles of levee work along the Wabash River.

From 1905 until 1916, Mr. Spiker was engaged in the general practice of engineering in Southern Illinois and Indiana and Southeastern Missouri. In 1916, he was appointed Chief Engineer of the Brevoort Levee System, in charge of its design and construction. He was also engaged as Engineer in the straightening of the Patoka River in Pike and Gibson Counties, Indiana.

From 1918 to 1922, Mr. Spiker served as City Engineer of Vincennes, and from 1922 until his death, was actively engaged in the general practice of engineering and as Chief Engineer of the Little Black River Drainage District in Southeastern Missouri. He also took a prominent part in construction work in Kentucky where he contracted his last sickness. Surviving him are his wife and one son.

Mr. Spiker was elected a Member of the American Society of Civil Engineers on February 4, 1914. He was also a member of the Western and Indiana Engineering Societies.

* Memoir prepared by A. C. Spiker, M. Am. Soc. C. E., and Noble Spiker, Esq.

EDWARD CHANDLER TOLLINGER, M. Am. Soc. C. E.*

DIED JUNE 18, 1924.

Edward Chandler Tollinger, the son of George Washington and Margaret Jane Tollinger, was born in Lancaster County, Pennsylvania, on September 20, 1844. He received his education in the schools of Lancaster County and attended the Pennsylvania State Normal School at Millersville, Pa. He served in the Union Army during the Civil War. After the war he began his professional career as a Rodman on railway work, and from then until his death, Mr. Tollinger was actively engaged in the practice of civil engineering.

From 1869 to 1873, he was with the Chicago and Alton Railroad Company, serving from June, 1869, to July, 1870, as Rodman and Instrumentman, and from 1870 to 1873, as Assistant Engineer in general charge of construction on 65 miles of line in Illinois and 102 miles in Missouri.

During 1873 and 1874, he constructed 5 miles of levee, on the Mississippi River (Sny Island Levee in Missouri). From July, 1875, to August, 1876, he was Assistant Engineer and Masonry Inspector on the St. Louis, Keokuk and Northern Railroad, and from 1877 to 1880, Superintendent of Construction and Assistant Engineer on the Muscle Shoals lock and dam construction on the Tennessee River, where he completed Locks Nos. 3 and 4 and started construction on Lock No. 2.

Mr. Tollinger held the position of General Manager and Superintendent for the Keokuk Hydraulic Mining Company at Keokuk, Iowa, from 1881 to 1883, and as such constructed a reservoir, flumes, approximately 14 miles of ditch, and other work connected with the project. While thus employed, he also served during the winter season in the Third Mississippi River Commission District on channel work and revetment construction.

In 1884, Mr. Tollinger accepted permanent employment with the Mississippi River Commission as Assistant Engineer, and from 1884 to 1886, was engaged on channel improvement and revetment work. In 1886, he was assigned as Assistant Engineer in charge of levee construction in Arkansas and Louisiana (Upper Tensas Levee District).

From 1886 until his death, he was actively in charge of levee construction and maintenance in the Third Mississippi River Commission District, covering one or both of the Levee Districts comprising 426 miles of levee in Mississippi, Arkansas and Louisana.

Although eligible for retirement, Mr. Tollinger, by recommendation of the various District Engineers and the members of the Mississippi River Commission, was retained in active service, and, until the beginning of his last illness, was relied on for expert administration and advice in the layout and conduct of all levee work performed by the Government in the Third District. His services were particularly valuable during times of flood emergency; he was always resourceful and never gave up the fight. To his credit more than to any other man is ascribed the successful maintenance of the levee lines throughout scores of high-water periods.

* Memoir prepared by A. M. Todd, M. Am. Soc. C. E.

Mr. Tollinger was very popular with all his associates and acquaintances, and he leaves a host of friends, not only in the territory in which he served and lived from day to day, but throughout the whole country. He was also well known, and many will miss his kindly and genial personality. He was most generous with his means and always could be relied on to help the deserving, but his modesty prevented many of his kindly acts from being generally known.

Mr. Tollinger is survived by three brothers, L. Tollinger and C. Tollinger of Delavan, Ill., and George Tollinger, of Pennsylvania, and by two sisters, Mrs. S. J. Elliott and Mrs. Leonard W. Lee, both of Oxford, Pa.

He was a member of the American Society of Military Engineers, the National Geographic Society, and the Benevolent and Protective Order of Elks. He was also a member of and Elder in the Presbyterian Church.

Mr. Tollinger was elected a Member of the American Society of Civil Engineers on June 4, 1902.

GEORGE CHANDLER WHIPPLE, M. Am. Soc. C. E.*

DIED NOVEMBER 27, 1924.

The profession of Sanitary Engineering lost one of its most brilliant leaders in the death of Professor Whipple on November 27, 1924. Although he was thoroughly trained for his life's work, like many others, he was distinguished particularly for his powers of concentration, his unswerving devotion to his chosen profession, and the variety and extent of his accomplishments.

George Chandler Whipple was born at New Boston, N. H., on March 2, 1866. He was graduated from the Massachusetts Institute of Technology in 1889. In his Senior year at the Institute, he was a pupil of Professor W. T. Sedgwick from whom he received some of the inspiration for sanitary study and research which characterized his subsequent career. At that time, a force of well-trained men was being organized at Chestnut Hill Reservoir, a distributing reservoir within the city limits, to ascertain the reasons for some of the bad tastes in the water supplies of Boston, Mass. Mr. Whipple was one of the Principal Assistants in this work. He was employed in microscopical and other investigations and soon showed the results of his fine training. He developed an originality for designing apparatus to aid in the work and a faculty for perseverance in his researches which required little stimulus.

It was at this time that he invented many improvements in the methods of collecting and examining samples from different sources of supply and at different depths. This work led finally to the publication of his masterly book on "The Microscopy of Drinking Water" which went through several editions and was re-written and enlarged from time to time.

This remarkable book is perhaps one of the best among the monuments that remain to his memory. It gives an idea of the care and skill which he

* Memoir prepared by Desmond FitzGerald, Past-President and Hon. M., Am. Soc. C. E.

brought to bear on the many problems submitted to him for solution. It discusses methods of collection of samples for microscopical examinations; organisms found in lakes and reservoirs and their effects on odors, tastes, etc.; and covers questions connected with different methods of construction of reservoirs and their influence on the quality of supplies. In addition to this classical work, Professor Whipple published other books on such matters as "The Value of Pure Water" and "Typhoid Fever—Its Causation, Transmission, and Prevention".

In a comparatively short time, he rose to an important position among the sanitarians of the United States and became associated in business with Allen Hazen, M. Am. Soc. C. E., also a leading sanitary engineer in New York, N. Y., the firm name Hazen and Whipple, being distinguished in the practice of Sanitary Engineering.

In 1911, Professor Whipple was honored by Harvard University, where a Chair of Sanitary Engineering was created for him and he became Gordon McKay Professor of Sanitary Engineering there and at the Massachusetts Institute of Technology.

In 1917, there appeared a summary of the public health movement in Massachusetts in three volumes, the result of his indefatigable zeal.

Professor C. E. A. Winslow, himself a distinguished sanitarian, has added the following brief summary of Professor Whipple's life work, which expresses a sympathetic appreciation of his accomplishments. He writes:

"Whipple conferred upon the discussion of the most technical problem a breadth of vision and a background of culture which gave a unique quality to all that he did. The untimely end of his life is a heavy blow to us all; but it was a life rich in useful service and full of the inner serenity and the outward helpfulness of a soul at peace with itself and in key with universal law."

He was married to Mary E. Rayner, of Chelsea, Mass., in 1893, and soon thereafter chose Cambridge as his permanent residence.

Professor Whipple was elected an Associate Member of the American Society of Civil Engineers on September 6, 1899, and a Member on October 6, 1908.

WILLIAM STUART BABCOCK, Assoc. M. Am. Soc. C. E.*

DIED JULY 17, 1924.

William Stuart Babcock, the son of Charles B. and Amelia (Hopkins) Babcock, was born at Evansville, Ind., on December 10, 1862. He received his technical education at the Massachusetts Institute of Technology where he specialized in Architecture and from which he was graduated in 1883.

From 1883 to 1884, Mr. Babcock was associated with Reid Brothers, Architects, at Evansville, and in 1884 and 1885 he was employed in the office of the Supervising Architect in Washington, D. C.

* Memoir compiled from material on file at the Headquarters of the Society.

In 1886, he entered the service of the New York, New Haven and Hartford Railroad Company, in charge of the design and general superintendence of stations, shops, roundhouses, offices, and freight houses.

From 1886 until 1904, when he resigned his position with the Railroad Company, Mr. Babcock designed passenger stations, engine and freight houses in various cities and towns in Massachusetts, Rhode Island, Connecticut, and New York. He also made changes in the Company's Pier 19 at New York, N. Y., and designed an icing plant at Poquonock, Conn.

In 1904, he entered the service of the Barrett Company, of New York, as Special Water-Proofing Engineer, which position he retained until 1923, when he removed to Los Angeles, Calif. Being in ill health, however, he was unable to engage in business. He died at his new home on July 17, 1924.

Mr. Babcock was married at Huntington, N. Y., on October 26, 1907, to Louise Knapp Kane, who died in 1915. Two sons, Stuart Kane and Frederick Lloyd Babcock, survive him.

He was a member of the American Society for Testing Materials, the Engineers Club, the Technology Club, and the Railroad Club of New York. He was also a member of the Protestant Episcopal Church and, in politics, was a Republican.

Mr. Babcock was elected an Associate Member of the American Society of Civil Engineers on February 1, 1905.

GEORGE ALLEN KYLE, Assoc. M. Am. Soc. C. E.*

DIED NOVEMBER 17, 1924.

George Allen Kyle, the son of Z. D. and Comfort O. Kyle, was born at Tobasco, near Cincinnati, Ohio, on September 21, 1857.

Mr. Kyle began his professional career in July, 1876, and from that time until 1895, was engaged in railroad work, as follows: With the Cincinnati and Eastern Railway Company, as Chainman and Instrumentman on surveys and construction; the Chicago, Belleville, Cascade and Western Railroad Company, as Levelman on surveys and construction; the Chicago, Milwaukee and St. Paul Railway Company, as Instrumentman on the Sabula Bridge, over the Mississippi River, between Savanna, Ill., and Sabula, Iowa, Transitman on surveys, and Resident Engineer in charge of the construction of two 15-mile sections of the road; the Cincinnati and Eastern Railway Company, as Locating Engineer and Resident Engineer on the construction of 20 miles of that line in Ohio; the Dubuque and Northwestern Railway Company as Locating Engineer; the St. Paul and Northern Pacific Railroad Company, as Topographer; the Chicago and Evanston Railway Company as Instrumentman; the St. Paul and Northern Pacific Railroad Company, as Resident Engineer in charge of 5 miles of the road; the Dakota, Duluth, Watertown and Pacific Railroad Company as Locating Engineer; the Chicago, St. Paul and Kansas City Railroad Company as Locating Engineer in charge of 40 miles of that line; the Union Pacific Railroad Company, as Locating Engineer

* Memoir prepared by R. F. Heckman, Esq., San Francisco, Calif.

in Wyoming, Nevada, and California; and the Northern Pacific Railroad Company, as Locating Engineer, Resident Engineer, and Assistant Engineer in charge of the construction of part of the Grays Harbor Branch in Washington and the Wallace Branch in Idaho.

In 1895, Mr. Kyle went to South Africa with Mr. John R. Stephens, as Engineer in charge of tunnels on the Simmer and Jack Gold Mining Properties in the Transvaal. He remained in this position until the Jamieson Raid (in which he took part) when he was forced to leave the country. He then returned to the United States and to the employ of the Northern Pacific Railway Company. In 1897, he held the position of Assistant Engineer in charge of the construction of the Belmont Branch in Manitoba, Canada, and, in 1898, was in charge of surveys in Southeastern Washington. From December, 1898, to December, 1900, he had charge of surveys and the construction of the Palmer Cut-Off, an important main-line change near Seattle, Wash., and shortly afterward was made Division Engineer of the Western Division, in which capacity he served until 1902.

At this time the Grand Trunk Pacific Railway was started with Mr. Stephens as Chief Engineer and Mr. Kyle went with that Company as Principal Assistant Engineer. He remained in this position until 1904 when the agitation against the employment of American engineers on work financed by the Canadian Government forced him to resign and he returned to the United States. He was employed on special work for the Northern Pacific Railway Company for a few months and then went to Alaska as Chief Engineer for the Alaska Central Railway. Surveys were made from Seward to Fairbanks, and about 40 miles of line from Seward to Anchorage was built and is now a part of the Government Railway. Government interference and the failure of a Canadian bank largely interested in financing this project forced the stoppage of all work, and Mr. Kyle returned to Seattle where he was made Assistant Chief Engineer of the western part of the Puget Sound Extension of the Chicago, Milwaukee and St. Paul Railway. He remained in this position until the completion of the work, when he was made Chief Engineer of the Oregon Trunk Railway of which John F. Stevens, Hon. M. Am. Soc. C. E., was President. Shortly afterward Mr. Kyle became Vice-President and General Manager of the Oregon Trunk Railway and the Oregon Electric Railways, which positions he held until 1911 when he resigned to enter private practice in Portland, Ore.

In 1916 Mr. Kyle went to China as Chief Engineer of the Chinese Government Railways in charge of the Siems-Carey Projects. Surveys were made from the Yangste River south to the South China Sea, approximately 1 000 miles, and from the Pekin-Hankow Railway west to Szechuan Province, approximately 1 000 miles. In 1918, while on a reconnaissance trip, he was captured by Chinese bandits, remaining a prisoner for 52 days in very grave danger. This experience had a great deal to do with hastening his death, as he never fully recovered from it. In 1919, all work on the Siems-Carey Projects ceased, and Mr. Kyle returned to the United States.

In 1920, and until 1922, he was connected with the late J. W. Kendrick, M. Am. Soc. C. E., on a proposed railway in Brazil. From 1923 to his death

on November 17, 1924, he was engaged as a Consulting Engineer in private practice on the Pacific Coast with an office in San Francisco, Calif. His home in Berkeley, Calif., and all his effects were destroyed in the fire of 1923.

Mr. Kyle's love for outdoors fitted him admirably for the positions he held during his life. He had unusual ability as a mathematician and was possessed of a keen mind, and was without doubt one of the best railway location and construction engineers of his time. This estimate has been confirmed by E. J. Pearson, M. Am. Soc. C. E., who writes as follows:

"He was possessed of the ability, in a remarkable degree, to visualize the relationship of these features, remotely distant, controlling the development of supported grades of unusual length; to associate with each other, within immensely large areas, the opportunities and the restrictions incidental to the topography over an extended range; and through this natural ability, Mr. Kyle's success as a Locating Engineer, was marked. His appreciation of his associates was deep and keen; his loyalty to them unquestioned; and his own abilities were always supplemented by effective co-operation".

On June 18, 1893, he was married to Mildred Corbin, of St. Louis, Mo., who, with two sons, Marion and Hugh, and one daughter, May, survives him.

Mr. Kyle was elected an Associate Member of the American Society of Civil Engineers on February 2, 1892.

ALONZO CHURCH LEE, Assoc. M. Am. Soc. C. E.*

DIED SEPTEMBER 1, 1923.

Alonzo Church Lee, the son of Alonzo Church and Sallie Whitmore Lee, was born in Columbus, Miss., on July 16, 1888. On his mother's side, Mr. Lee was of English-Virginia ancestry, related to the Epes family and to Thomas Jefferson. On his father's side he was descended from the South Carolina branch of the Lee family, his father being a double cousin of Gen. Stephen D. Lee. One of his paternal great-grandfathers, Dr. Alonzo Church, was a noted educator of the South, who for thirty years was President of the University of Georgia. Mr. Lee was proud of his ancestry and felt that in it he had a heritage which was at once an obligation and an inspiration.

Church Lee, as he was called by all who knew him well, received his early education in the public schools of Mississippi. Later, he attended Mississippi College, a preparatory school at Clinton, Miss. He studied for two years at Tulane University, New Orleans, La., and after four years of work at the University of Mississippi, received in 1911 from that institution the degree of B. E. in C. E. Five years later, on the presentation of a thesis on "Muscle Shoals", his Alma Mater bestowed on him the degree of C. E.

Mr. Lee's first experience in engineering work was during 1907-08—the year that elapsed between his leaving Tulane and entering Mississippi University. This year was divided between inspection of lock and dam construction on Ouachita River under the United States Engineer Department and general office and field work under the City Engineer of Jackson, Miss. There-

* Memoir prepared by W. S. Winn, Assoc. M. Am. Soc. C. E.

after, he worked during vacation periods with the City Engineers of Jackson and Oxford, Miss., and with the Illinois Central Railroad Company. In his Junior year, he was a Student Assistant Instructor in Surveying and Drafting.

On graduation, Mr. Lee again served as Inspector on the Ouachita River until the flood period stopped work when he was employed by the Tennessee Coal, Iron and Railroad Company in connection with construction of a modern mine surface plant at Edgewater, Ala. From July to October, 1912, he was Concrete Inspector on tunnel and power-house construction at Tallulah Falls, Ga. He then spent three months, until the work was completed, laying out and supervising a concrete pile foundation for a seventeen-story office building in Atlanta, Ga. Afterward, Mr. Lee was engaged for two months with the Sloss-Sheffield Steel and Iron Company on mine plant construction when he resigned to accept a position with the Engineer Corps of the U. S. Army, as Chief of Party on the Cumberland River, first on a precise level survey, and, later, on a topographic survey and lock and dam location, in preparation for the extension of the canalization of the river. In April, 1915, he was transferred to work on the Tennessee River where he assisted in the field and on preliminary plans for the development of power and improvement of navigation of the Muscle Shoals District.

On the completion of the Muscle Shoals investigations, Mr. Lee decided to enter a branch of his profession which would provide a more permanent employment, and accordingly took the Sales Course at four of the plants of the Ingersoll-Rand Company. In December, 1916, he became connected as Sales Engineer with the Company's office in Birmingham, Ala.

When the United States became involved in the World War, Mr. Lee at once responded to the call of the blood of his warrior ancestors, and in August, 1917, was admitted to the training camp at Fort Oglethorpe, Georgia. On November 27, 1917, he received a commission as First Lieutenant of Infantry and was assigned to the 17th Machine Gun Battalion. His principal stations in this country were Chickamauga Park, Georgia; Camp Wadsworth, South Carolina; Camp Mills, New York; and Camp Dix, New Jersey. In July, 1918, he went overseas, where he took part in the Meuse-Argonne drive. Returning to the United States a year and ten days later Mr. Lee was honorably discharged from the Army on August 6, 1919, and immediately returned to the service of the Ingersoll-Rand Company, being attached to its St. Louis office. After three years, however, he resigned on account of ill health and went to Southern California where he engaged in the real estate business, hoping that a change of work and climate would restore his health.

On September 1, 1923, he went for a swim with a friend at the Santa Monica, Calif., bathing beach. Mr. Lee was in his usual good spirits. When the time came to leave the beach, the two who had been sunning in the sand raced to the ocean for a final dip. The friend came out, but Mr. Lee was never seen alive again and no one knows just how he was drowned. His body, recovered a few days later, was cremated as he had requested it should be, and his ashes were scattered with white roses on the ocean to which he had forfeited his life.

Mr. Lee was well equipped mentally, morally, and physically, to meet the struggles of life. Descended from educators and college-bred ancestors on both sides of his family, he early determined to have a college education and secured it largely by his own efforts. In his youth he joined the Presbyterian Church and remained a consistent member until his death. He was a Knight Templar, and a member of the American Legion and of the Kappa Alpha Fraternity.

He was a clean-cut athlete and loved all kinds of sports. He was recognized as one of the most brilliant athletes the University of Mississippi ever produced, starring as Captain of the basket-ball team and as Fullback in the "Ole Miss" football team of 1910. He carried a full measure of enthusiasm into whatever he was doing—whether work or play. With all his strength and fighting vim, his heart was as tender as that of a child. His devotion to and tender care of his mother was beautiful to see. He was unmarried and is survived by his mother and a younger brother, Frank W. Lee, of Tulsa, Okla.

Mr. Lee was elected an Associate Member of the American Society of Civil Engineers on June 23, 1916.

ARTHUR DICKSON PRINCE, Assoc. M. Am. Soc. C. E.*

DIED JANUARY 21, 1925.

Arthur Dickson Prince, the son of Christopher Prince, Jr., and Julia Dickson Prince, was born at Glen Cove, Long Island, N. Y., on October 21, 1870. He was the twelfth in the direct line of descendants to inherit the estate on which he was born and where his death occurred, this property having been purchased by his ancestors directly from the Indians.

At the age of nineteen, he entered the old School of Mines of Columbia College, now Columbia University, and was graduated with his class in 1893 with the degree of Civil Engineer. While at Columbia he took an active and prominent part in college activities, rowing on his Freshman and the three succeeding "Varsity" crews of the College. He continued his activity in sports, being an ardent yachtsman, competing in many races on Long Island Sound and winning many prizes.

Following his graduation, Mr. Prince was employed as Superintendent of the George F. Swift Construction Company on contract work in New York, N. Y., as Draftsman for Professor H. S. Munroe, of Columbia College, on coal mining work, and from March, 1894, to March, 1896, by the Metropolitan Traction Company on the construction of the Lexington Avenue Cable Road of New York, in responsible charge of a part of the construction of this road. From the spring of 1896 until the fall of 1900, he was in the employ of various Departments of the City of New York in the capacity of Assistant Engineer in charge of construction.

On the formation of the Engineering Department of the Board of Rapid Transit Commissioners, organized for the construction of New York's first

* Memoir prepared by George Hallett Clark, M. Am. Soc. C. E.

subway, Mr. Prince was transferred to that organization as Assistant Engineer on October 1, 1900, and was assigned to the First Division. He continued his connection with this Division until the time of his death, having served for the past fifteen years as Senior Assistant Division Engineer.

In 1905, previous to the construction of the tunnel of the Pennsylvania Railroad under the 33d Street Station of the Fourth Avenue Subway, Mr. Prince was designated to conduct investigations relative to recording the vibrations caused by the blasting to be done in tunneling beneath the subway. He designed and constructed an instrument on the principle of the vertical pendulum seismograph for recording amplitude and period of vibrations, in three directions. This instrument was operated, during the period of blasting operations in the Pennsylvania Tunnels in the vicinity of the Fourth Avenue Subway and recorded successfully the vibrations caused by this blasting. A notable occurrence in the operation of the instrument was the recording of the major earthquake shock which destroyed the City of San Francisco, Calif., in April, 1916, the violence of the earth movement having been sufficient to swing the recording needle outside the edge of the record sheet. This instrument was later operated in the Times Building for recording vibrations due to the operation of subway trains and in several other buildings adjacent to subways. At present, it is on loan to the United States War Department and is being used in the Astoria Gas Tunnel in connection with blasting in the East River.

In a service of twenty-five years with the City of New York in the development of its rapid transit facilities, Mr. Prince has typified the trained and educated Engineer whose ability, constantly increasing knowledge of special conditions, and devotion to duty have made possible the prosecution of great public works to successful completion, notwithstanding the inevitable changes in the directing personnel of City and State Commissions.

On June 7, 1900, Mr. Prince was married to Emily Jackson, who with a son, James D. Prince, survives him.

Mr. Prince was elected a Junior of the American Society of Civil Engineers on May 5, 1896, and an Associate Member on October 3, 1900.

KENNETH LOUIS GREEMAN, Jun. Am. Soc. C. E.*

DIED AUGUST 21, 1924.

Kenneth Louis Greeman, the son of Louis F. and Ida W. Greeman, was born in Batesville, Ind., on September 19, 1900. In his early childhood, his parents moved to Seymour, Ind., where he received his elementary education. He was graduated from the High School at Seymour in June, 1917, and entered Purdue University, West Lafayette, Ind., the following September, from which he was graduated four years later with the degree of Bachelor of Science in Civil Engineering. He was elected to membership in Tau Beta Pi at Purdue.

* Memoir prepared by E. R. Feldman, Esq., Auburn, Ind.

While in college, Mr. Greeman spent his summer vacations in the pursuit of his chosen vocation. From June, 1918, to January, 1919, he served as Rodman with the Maintenance of Way Department of the Baltimore and Ohio Railroad in West Virginia.

After completing his college work, Mr. Greeman accepted a position as Assistant Engineer of Design with the Department of Bridge Construction of the Indiana State Highway Commission. With the exception of four months spent in the supervision of the construction, for the State, of a reinforced concrete arch bridge, designed by himself, Mr. Greeman continued in this position until May, 1923, when he resigned to accept a position as Designer with the Gabriel Steel Company, at Detroit, Mich. In September, 1923, he received an appointment as an Instructor in the Department of Theoretical and Applied Mechanics at the University of Illinois, Urbana, Ill., which position he held until June, 1924.

After having spent the summer in the employ of the Gabriel Steel Company, Mr. Greeman, with his family, was driving from Detroit to Terre Haute, Ind., where he had accepted an instructorship in the Department of Civil Engineering of Rose Polytechnic Institute. Their automobile was struck by a traction car near McCordsville, Ind., and Mr. Greeman and his infant son were instantly killed, while his wife was seriously injured.

In 1922, Mr. Greeman was married to Rita Watton, of Flint, Mich., and he is survived by his wife, his parents, and two brothers.

Mr. Greeman was elected a Junior of the American Society of Civil Engineers on January 16, 1922.